ARIZONA DEPARTMENT OF TRANSPORTATION

REPORT: ADOT-RS-14 (167) FINAL REPORT

LABORATORY AND FIELD DEVELOPMENT OF ASPHALT-RUBBER FOR USE AS A WATERPROOF MEMBRANE

July 1977

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16. Abstract

The research has been directed toward obtaining information on some of the physical properties of various asphalt-rubber (A-R) mixes as related to waterproof membrane applications. In particular, three rubber particle size distributions and three asphalt-rubber spread quantities were investigated.

Laboratory testing utilized for physical property determination included thin film permeability, water absorption (ASTM D570-72), Water Vapor Transmission (ASTM 96-72, procedure BW), ductility (ASTM D113-74), Tensile-Toughness, viscosity and slope stability.

The results of the study showed that the A-R as an integral membrane is relatively impermeable. The addition of the rubber does not affect the permeability of an otherwise homogeneous asphalt film. Physical property values of asphalt that are increased when rubber is added include water absorption, slope stability, toughness and viscosity. Those that exhibit lower physical property values include ductility and slope/flow characteristics.

Installation of experimental field plots provided additional positive information on the waterproofing characteristics of the A-R and also helped develop field procedures on A-R application to a prepared subgrade.

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Phoenix, Arizona

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Sponsored by
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May 1977

IMPLEMENTATION STATEMENT

In August 1977 a contract was awarded to complete construction of a low-volume traffic highway located in District VI. This section is identified as the Dewey-I-17 Highway from Yarber Wash to I-17 (F-058-501). This contract was limited to compacting the subgrade and constructing the top wearing course. Grade and drain was completed under a previous contract.

Test Sections on this project are as follows:

<u>Design A</u> - Control or Standard Section

Subgrade: Untreated, compacted to 100 percent densities.

Top Course: Two inch A.C. with four inch A.C. designated as "future".

<u>Design B</u>

Subgrade: Lime-Fly Ash stabilized six inches.

Interlayer: Asphalt-Rubber Membrane across entire roadway width, shoulders and cut ditches.

Top Course: One inch ACFC.

<u>Design C</u>

Subgrade: Cement Stabilized, six inches.

Interlayer: Asphalt-Rubber membrane across entire roadway width, shoulders and cut ditches.

Top Course: One inch ACFC.

<u>Design D</u>

Subgrade: Built to 100 percent densities with moisture controls.

Interlayer: Asphalt-Rubber membrane across entire roadway width, shoulders, and cut ditches; also in trenches 13 ft. from centerline to partially encapsulate subgrade.

Design D (con't)

Top Course: One inch ACFC

Design E

Subgrade: Stabilized and compacted with an enzymatic compaction aid.

Interlayer: Asphalt-Rubber membrane across entire roadway width, shoulders and cut ditches.

Top Course: One inch ACFC.

Subgrade moisture content was recorded during construction and will be monitored for a period of several years to evaluate the asphalt-rubber membrane's effectiveness. Data reporting will be processed as a Non-FA Construction Experimental Feature, "Dewey-Jct. I-17, F058-1-501", and Demonstration Project #37, "Discarded Tires in Highway Construction."

B.W. Ong
12/1/77

LABORATORY AND FIELD DEVELOPMENT OF ASPHALT-RUBBER FOR USE AS A WATERPROOF MEMBRANE

Abstract

The research has been directed toward obtaining information on some of the physical properties of various asphalt-rubber (A-R) mixes as related to waterproof membrane applications. In particular, three rubber particle size distributions and three asphalt-rubber spread quantities were investigated.

Laboratory testing utilized for physical property determination included thin film permeability, water absorption (ASTM D570-72), Water Vapor Transmission (ASTM E96-72, procedure BW), ductility (ASTM D113-74), Tensile-Toughness, viscosity and slope stability.

The results of the study showed that the A-R as an integral membrane is relatively impermeable. The addition of the rubber does not affect the permeability of an otherwise homogeneous asphalt film. Physical property values of asphalt that are increased when rubber is added include water absorption, slope stability, toughness and viscosity. Those that exhibit lower physical property values include ductility and slope/flow characteristics.

Installation of experimental field plots provided additional positive information on the waterproofing characteristics of the A-R and also helped develop field procedures on A-R application to a prepared subgrade.

INTRODUCTION

Objectives

Moisture barriers in highway construction are extremely important to the life of pavement structures and bridge decks. The advantage of using a waterproof membrane on bridge decks to prevent moisture and deicing chemicals from entering and severely damaging the bridge structure is evident. As an interface between subgrade and base, a membrane prevents moisture from penetrating the highway structure and thus preventing structural damage. Also, waterproof membrane materials can be used to coat side slopes and drainage ditches to prevent infiltration of water into the highway structures.

Extensive laboratory and field work has been done or is being accomplished on asphalt-rubber* relative to its stress absorbing and/or engineering characteristics and mixture modification. Its use has been primarily in seal coat applications, crack filling operations and as a stress absorbing membrane interlayer (SAMI) within the pavement structure. The waterproofing characteristics of asphalt-rubber used in highway construction have been recognized (10,11).**

Arizona Department of Transportation (ADOT) research on asphalt-rubber has thus far been limited to the use of one rubber particle size, TP.044 (#16 to #25 mesh), in the mix which incorporates one part rubber to three parts asphalt. Also incorporated in the ADOT mix is 5 to 7% kerosene which provides a desirable spraying viscosity.

This research effort has been directed towards varying the rubber particle size distribution in an effort to detect a variance in some of the

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*The Asphalt-Rubber mix will frequently be referred to as A-R throughout the text.

**The number in parenthesis corresponds to the reference citation listed at the end of this report.

physical properties of the asphalt-rubber mix as related to waterproof membrane applications. The three particle size distributions chosen were TP.044, TP.027 and a 50/50 mix of TP.044 and TP.027. Figure 1A of Appendix A represents the typical particle size distributions utilized in the A-R testing. The total percentage (by weight) of rubber was not changed but remained at one part rubber to three parts asphalt. Also varied in some of the testing was the membrane thickness in an attempt to determine the effect of application rate on waterproofing properties. Kerosene was omitted from all testing related to waterproofing characteristics due to its detrimental effects on the physical properties of the A-R mix and difficulty in laboratory molding and testing.

An extensive literature search indicated that very little documented research has been done on asphalt-rubber which incorporates a relatively large percentage of granulated rubber. Most published information pertains to actual field demonstrations of highway applications. Literature on testing materials of the A-R type of composition was also very limited. Consequently, there were extremely limited guidelines to be found for this project.

Procedure

The base asphalt and vulcanized rubber were supplied by the Arizona Department of Transportation. Material specifications are presented in Appendix A. After the materials were obtained, samples were mixed and run through a series of tests as shown in Fig. 1. The mix procedures and test methods are described in the following section.

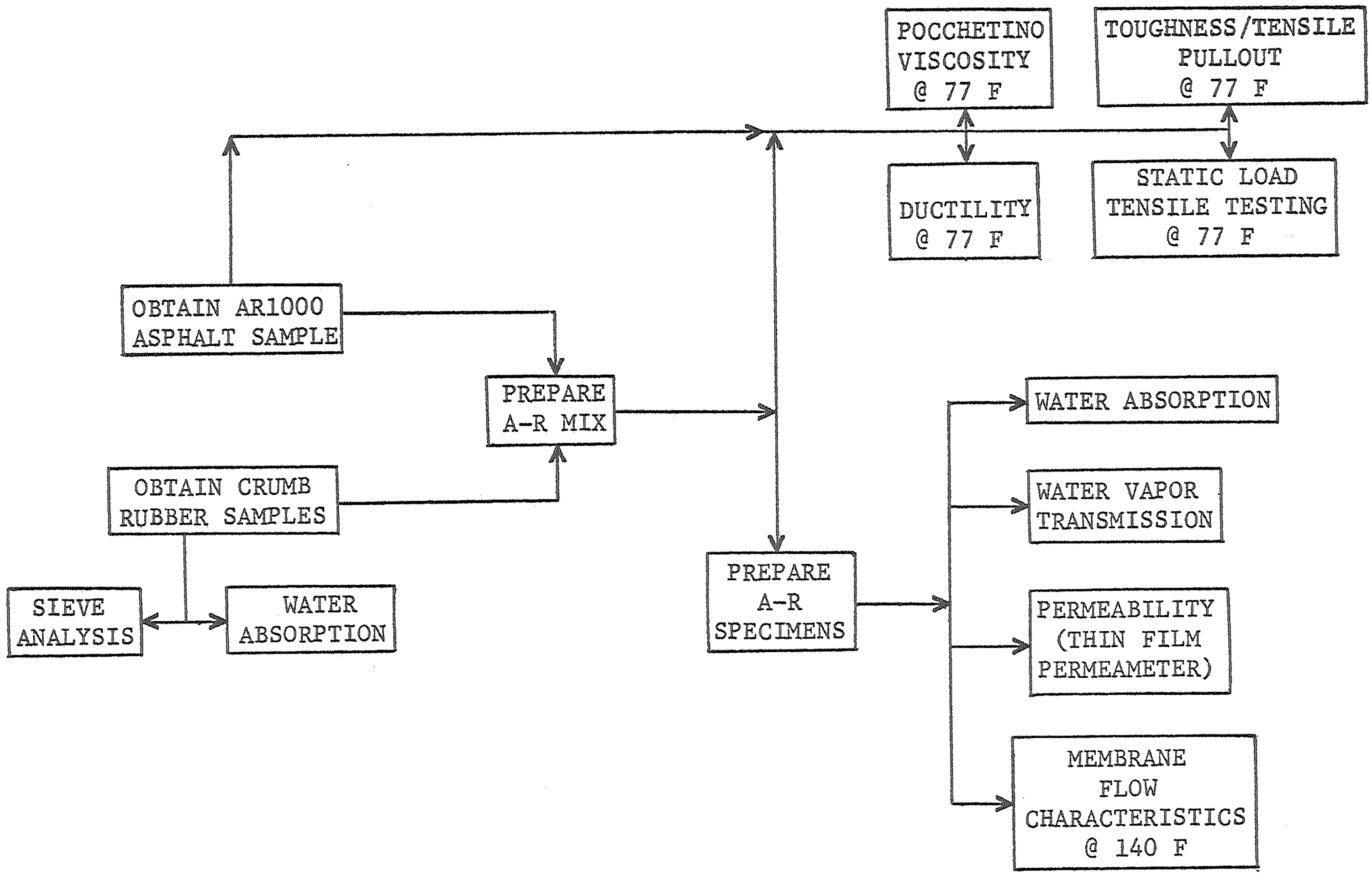


Figure 1. Flow Chart for Asphalt-Rubber Testing

TEST METHODS

The following sections describe the mix procedures and methods used in the A-R testing. The actual techniques employed for a standard ASTM documented test procedure are not included but the number of the standard will be given as reference.

Mix Procedures

All test methods used in this study incorporated the same mix procedures for sample preparation. The procedures were as follows:

1. Bring the base asphalt to 375^{0}F (190^{0}C) utilizing a constant heat device such as a hot plate or ring burner. Use a seamless, stainless steel crucible large enough to mix a minimum of 1000 grams of A-R.
2. Add the granulated rubber as rapidly as possible over a period of 5 minutes, stirring constantly.
3. Continue stirring the mix for 30 minutes. The temperature during mixing must be held between 350-375^{0}F (176-190^{0}C).
4. Pour the A-R mix directly into the desired mold or test apparatus. It is necessary to utilize mold release paper or silicone grease to prevent the A-R from sticking to some molds and test devices.
5. Allow molded specimens to cure at room temperature for a minimum of 24 hours before start of testing.

Water Absorption Tests

A-R Membrane. A standard testing method for water absorption of plastics was chosen as a viable test in an attempt to determine the relative rate of water absorption of the asphalt-rubber membrane when totally immersed in de-aired, distilled water. The test procedure followed was ASTM standard D570-72 (long-term immersion) (3). Specimen thickness was 3.4 mm $\pm$0.2 mm.

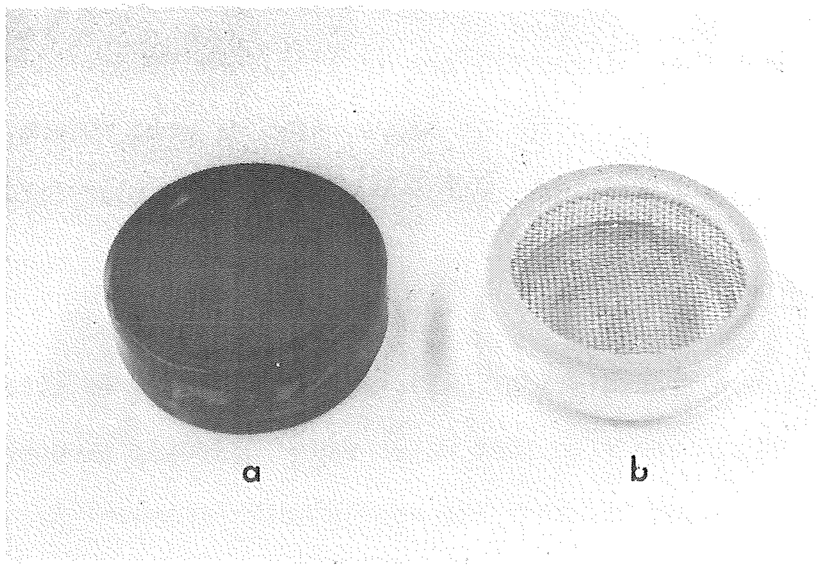
Granulated Rubber. Saturated samples of the rubber that were supplied by ADOT were run in a centrifuge in accordance with the Centrifuge Kerosene Equivalent (CKE) test procedures (1). The liquid medium used, however, was de-aired, distilled water and not kerosene as specified in the test procedures. This method was used in an attempt to determine the total water absorption of the rubber alone. Before testing, the rubber particles were placed in a 140°F (60°C) oven for 24 hours, samples were weighed and immediately placed in distilled, de-aired water for 24 hour saturation.

Water Vapor Transmission Testing

The Water Vapor Transmission (WVT) test was used in an attempt to determine the approximate rate that water vapor diffuses through various A-R membrane thicknesses and thus its approximate permeability. The standard test procedure chosen was ASTM E 96-72, procedure BW (4), which tests one wetted surface only.

Due to the nature of the A-R material and its susceptibility to flow, several modifications to the standard test apparatus and procedure were needed. The standard WVT test apparatus consists mainly of a small, light-weight plexiglass dish with a tight fitting restraining ring as shown in Fig. 2. The dimensions of the dish are 61 mm I.D., 10 mm depth and 300 mm^2 exposed surface area. The additional apparatus needed was a 20 mesh galvanized restraining screen to prevent flow of the membrane under test. The screen is normally not used in the standard ASTM E 96-72 test.

Generally, the test procedure consisted of filling the dishes with de-aired, distilled water, placing the A-R membrane over the surface and holding the



a - dish containing A-R test sample.
b - dish, ring and screen (assembled).

Figure 2. Water Vapor Transmission Test Dishes

membrane in place with the screen and restraining ring. Care must be taken to insure that no air is entrapped under the A-R membrane.

The ring was sealed to the dish and membrane with RC-250 asphalt to prevent edge failure. RC-250 asphalt was chosen as the best available seal after numerous trial WVT tests were run utilizing other asphalt, waxes and high vacuum grease. The entire assembly is inverted for the wetted surface effect and weighed periodically to determine weight loss as water vapor escapes through the membrane.

Preliminary testing indicated little or no weight loss when held in a constant temperature-humidity room. To facilitate a more rapid response, the WVT devices were placed in a small vacuum chamber at 10 in. hg (254 mm hg) as shown in Figure 3. The room temperature was kept at 77 ± 2^{0}F (25^{0}C). Approximately 50 grams of anhydrous, porous calcium chloride (4 mesh) were placed in the vacuum chamber in an attempt to maintain a relatively dry atmosphere.

Permeability Testing

This method of test covers an additional procedure used in an attempt to determine the coefficient of permeability of A-R by the constant head method. In general, an A-R sample membrane was placed in an apparatus with a constant head of water applied at one end. Flow through the A-R membrane was measured at the other end. The coefficient of permeability, K, in cm/sec can be calculated from Darcy's equation for one dimensional flow across a membrane.

Figure 4 illustrates the permeameter that was designed and fabricated for A-R testing. The actual test setup is shown in Fig. 5. System components include an air pressure regulator, water storage vessel, permeameter and graduated collector tube (burette).

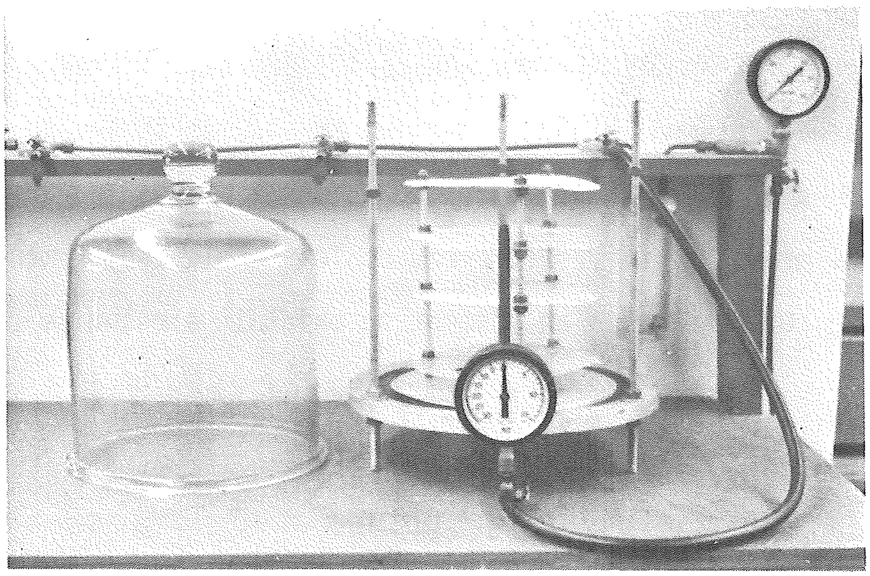


Figure 3. Vacuum Chamber Used in WVT Testing

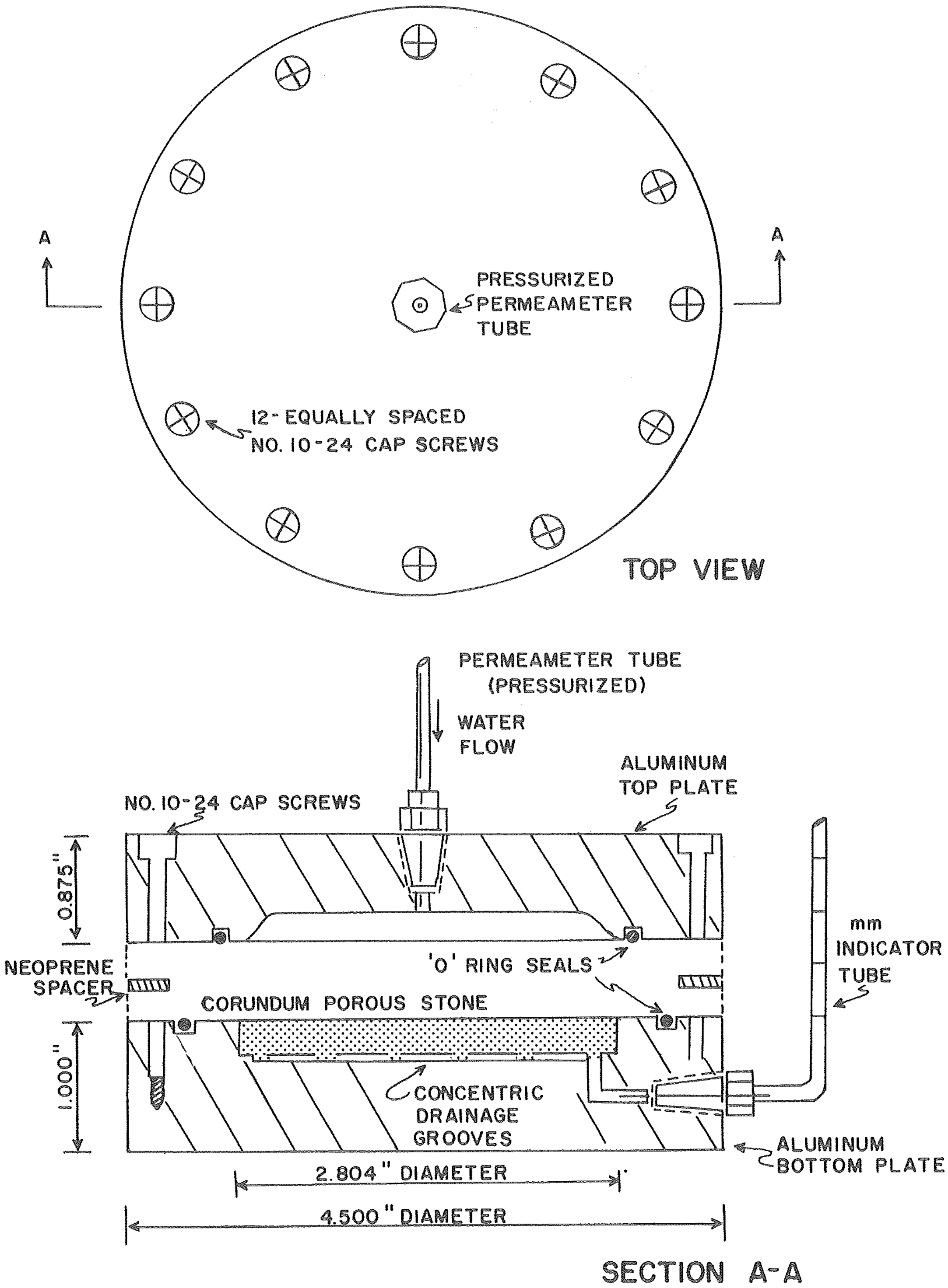
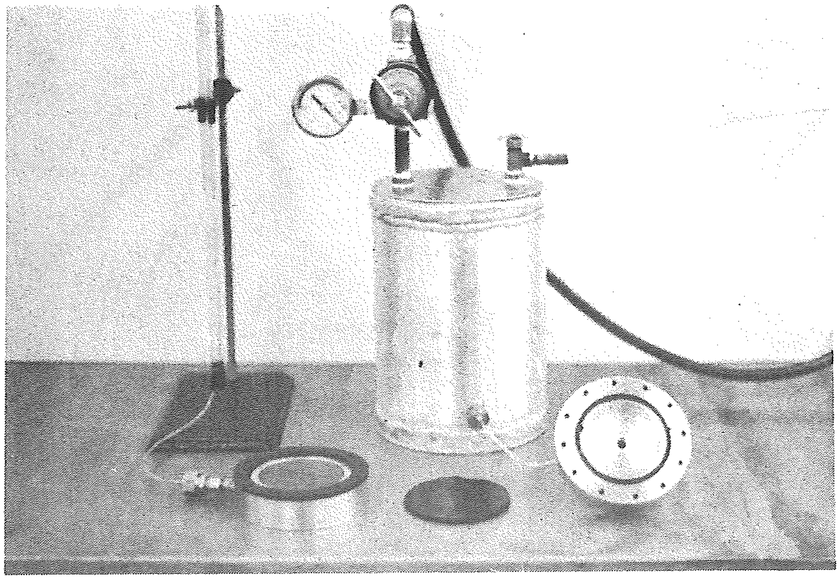
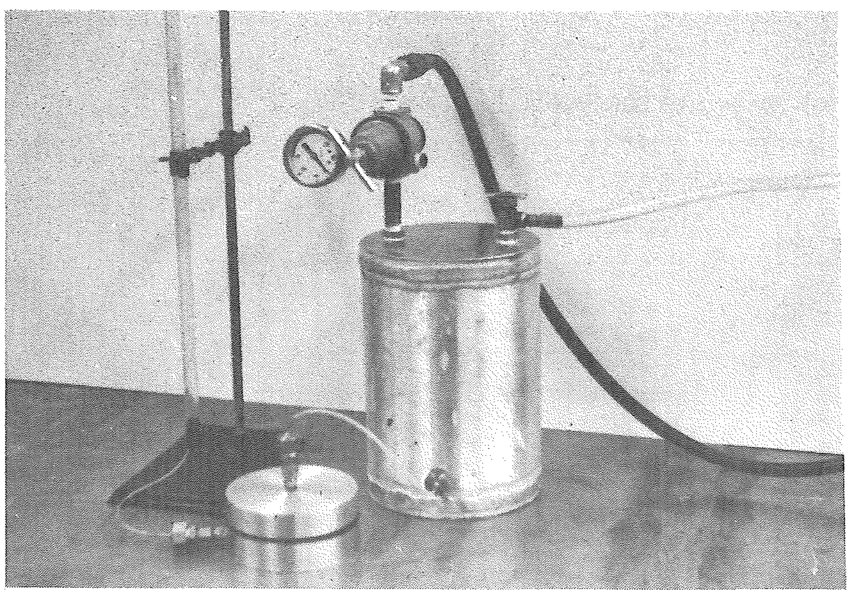


Figure 4. Static Head Permeameter



unassembled



assembled

Figure 5. Permeameter Test Apparatus

A desired sample mix was first molded to a given thickness (application rate) and the resulting membrane was allowed to cure at room temperature for a minimum of 24 hours. The 3.5 in. (88.9 mm) diameter specimen was placed over the porous stone in the bottom of the permeameter, the neoprene spacer ring positioned and the top plate bolted in place. A constant head of water was applied to the top of the membrane and flow through it was measured via the graduated burette. Care must be taken to insure that the permeameter is properly sealed to avoid leaks.

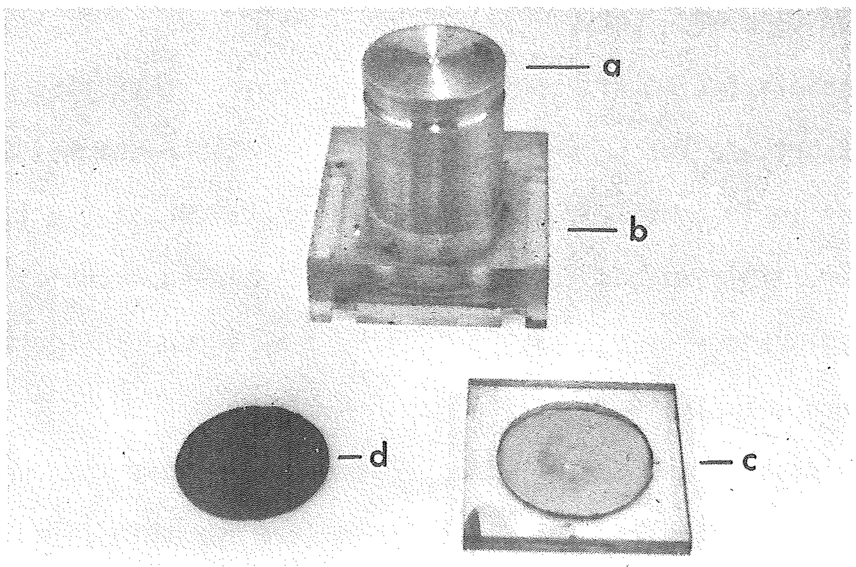
Due to the plastic nature of the asphalt-rubber, repetitive samples were difficult to fabricate for permeameter testing. A technique was devised whereby samples could be molded uniformly both in thickness (application rate) and in diameter. This method is simply a forced-molding technique utilizing a plexiglass mold and piston-sleeve arrangement as shown in Figure 6. The desired specimen weight ($\pm$0.1 gm.) of hot A-R mix is placed on the plexiglass mold and the piston forces the A-R to spread evenly across the contained mold diameter thus producing a repetitive specimen size for thin film testing. This same technique was used for water vapor transmission test specimens.

Ductility Testing

This test was used to determine the changes in relative ductility of the base asphalt and the various A-R mix combinations at 77^{o}F (25^{o}C). The standard procedures of ASTM D113-74 (5) were followed.

Toughness/Tensile Pullout Test

This test is a modification of one developed by Jewell R. Benson and described in the paper "Tentative Standard Method of Test for Toughness and Tenacity of Rubberized Asphalts" (6). Originally, the test procedure



a - piston
b - sleeve (centering block)
c - mold
d - finished specimen

Figure 6. Molding Apparatus for A-R Membrane Samples

was designed to test the toughness and tenacity of rubberized asphalt employing 3 to 5% liquid latex or powdered rubber. The objective in using this test was to attempt to determine the relative toughness or resistance to deformation of A-R mixes as compared to the base asphalt.

Equipment and Materials. The A-R mixes used in this study were plain AR 1000; AR 1000/TP.044, AR 1000/TP.027 and AR 1000/TP.027-044.

The apparatus designed and fabricated for this test procedure is shown in Fig. 7 and includes the following:

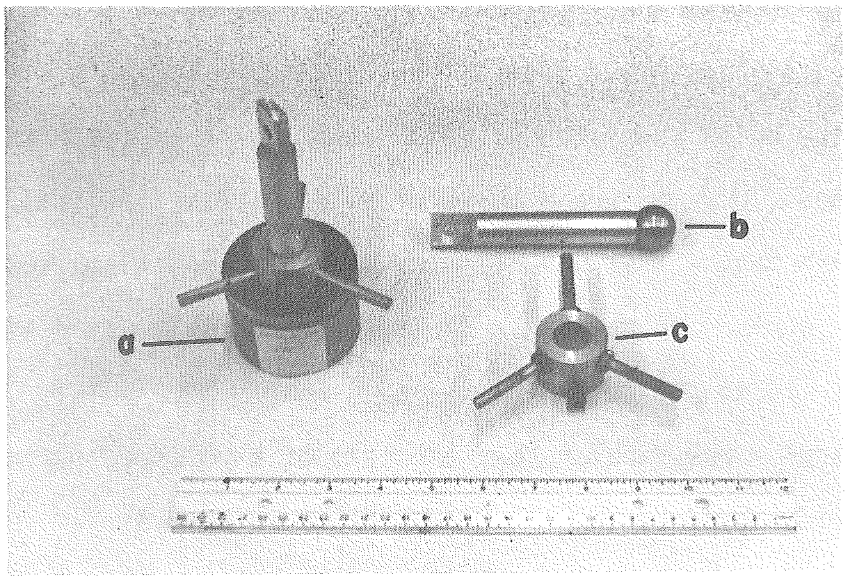
(a) Molds - the molds consisted of metal cans having an interior diameter of 3 inches (76.2 mm) and a depth of 1-1/2 inches (38.1 mm).

(b) Restraining base - this was designed to center and clamp the individual mold cups containing the A-R. The restraining base was designed to attach firmly to the testing machine.

(c) Tension head - the tension head consists of a polished stainless steel hemispherical head having a 1/2 inch (12.7 mm) radius and integrally attached to a 1/4 inch (6.4 mm) diameter rod designed to permit rapid connection to the testing machine head.

(d) Spider support - the spider was fabricated to provide accurate centering of the tension head into the mold and to provide vertical support for the tension head and connecting rod. The spider is provided with a restraining screw so that the hemisphere may be accurately imbedded into the sample mix. The spider is not physically attached to the mold can but rather provides centering and support only for the tension head.

An Instron Universal Testing Machine, Model TT-C with a 10,000 lb.(4536 Kg) capacity F-load cell was used for performing the Toughness/Tensile-Pullout tests. Samples were first conditioned at 77^{o}F (25^{o}C) with the use of a constant temperature water bath. They were then removed from



a - mold can
b - tension head
c - spider support

Figure 7. Toughness/Tensile Testing Apparatus

the bath and immediately tested.

Procedure. The A-R samples were mixed in accordance with previously described mixing procedures and immediately placed in the mold cans. The hemisphere was then positioned in the hot mix, centered in the mold and restrained by the spider support. After a cure time of 24 hours the samples and apparatus were placed in a water bath for a minimum of 2 hours. After conditioning, the samples were positioned between the upper and lower bars in the Instron testing machine as shown in Fig. 8 and immediately tested. For these tests, a crosshead speed of 20 inches per minute (559 mm/min.) was used as outlined by J. R. Benson's procedures (6). A high speed Leeds and Northrup graphic recorder was used to record the load vs. deformation when the hemisphere is pulled out of the A-R mix. The chart speed was also set at 20 inches per minute (559 mm/min).

Modified Barrett Slide Test

The modified Barrett Slide Test from the Bureau of Reclamation test procedures on filled asphalt cements was adopted for use in testing the A-R mixes (7). Utilizing this test, an attempt was made to determine the relative flow/slope stability characteristics of the various A-R mixes. In particular, the stiffening properties that the rubber particle size imparts to the A-R mix were investigated.

Equipment and Materials. The A-R mixes used in this test were plain AR 1000; AR 1000/TP.044, AR 1000/TP.027 and AR 1000/TP.027-.044. The apparatus used for this test procedure includes the following:

(a) Constant temperature oven.

(b) Brass molds which formed 1/2 inch (12.7 mm) cubes of A-R and consisted of interlocking brass sides.

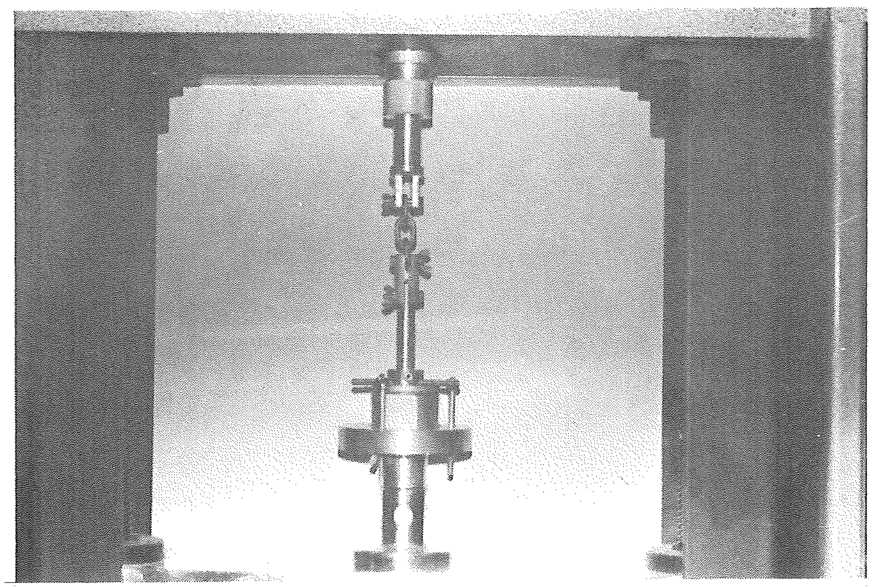


Figure 8. Toughness/Tensile Testing Apparatus
Positioned in the Instrom Model TTC

(c) V-notch copper slides and slope frame (see Fig. 9).

Procedure. The A-R samples were mixed in accordance with A-R mix procedures and immediately placed in the 1/2 inch (12.7 mm) cube molds. The molds were allowed to come to room temperature and then placed in a freezer at $32^{o}F$ ($0^{o}C$) for two hours to facilitate ease in specimen removal from the molds. The individual cubes were placed at the top of the copper slides (horizontal position) and allowed to come to room temperature of $77^{o}F$ ($25^{o}C$) for a period of not less than two hours. The entire slope assembly was placed in a preheated $140^{o}F$ ($60^{o}C$) oven for 48 hours at a 1-1/2 to 1 slope. At the end of 48 hours the displacements along the slope of the various A-R mixes were measured. A photograph of the assembly with specimens is shown in Fig. 9.

Viscosity Testing

The falling coaxial method of viscosity determination was chosen as a viable means for attempting to determine the relative viscosities of asphalt and asphalt-rubber mixes at $59^{o}F$ ($15^{o}C$), $77^{o}F$ ($25^{o}C$), and $104^{o}F$ ($40^{o}C$). Generally, the method used consists of the falling coaxial cylinder viscometer which had previously been studied extensively by Traxler and Schweyer (14). Based on their studies, a falling coaxial cylinder viscometer was built to use 10 to 100-second timing periods for viscosities ranging from 5000 to $1x10^{9}$ poises (14). The viscosities are determined mathematically from resulting shear stress and shear rate values obtained from the falling coaxial viscometer. A drawing of the viscometer is shown in Fig. 10 and consists of an outer brass ring and center aluminum piston upon which various weights are placed to provide different shear rates. The annular space between piston and ring is filled with asphalt cement or A-R.

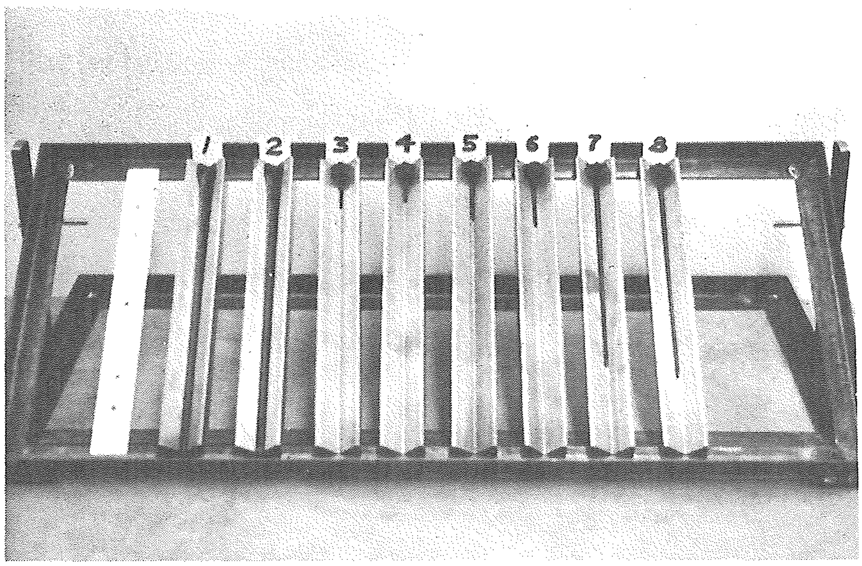
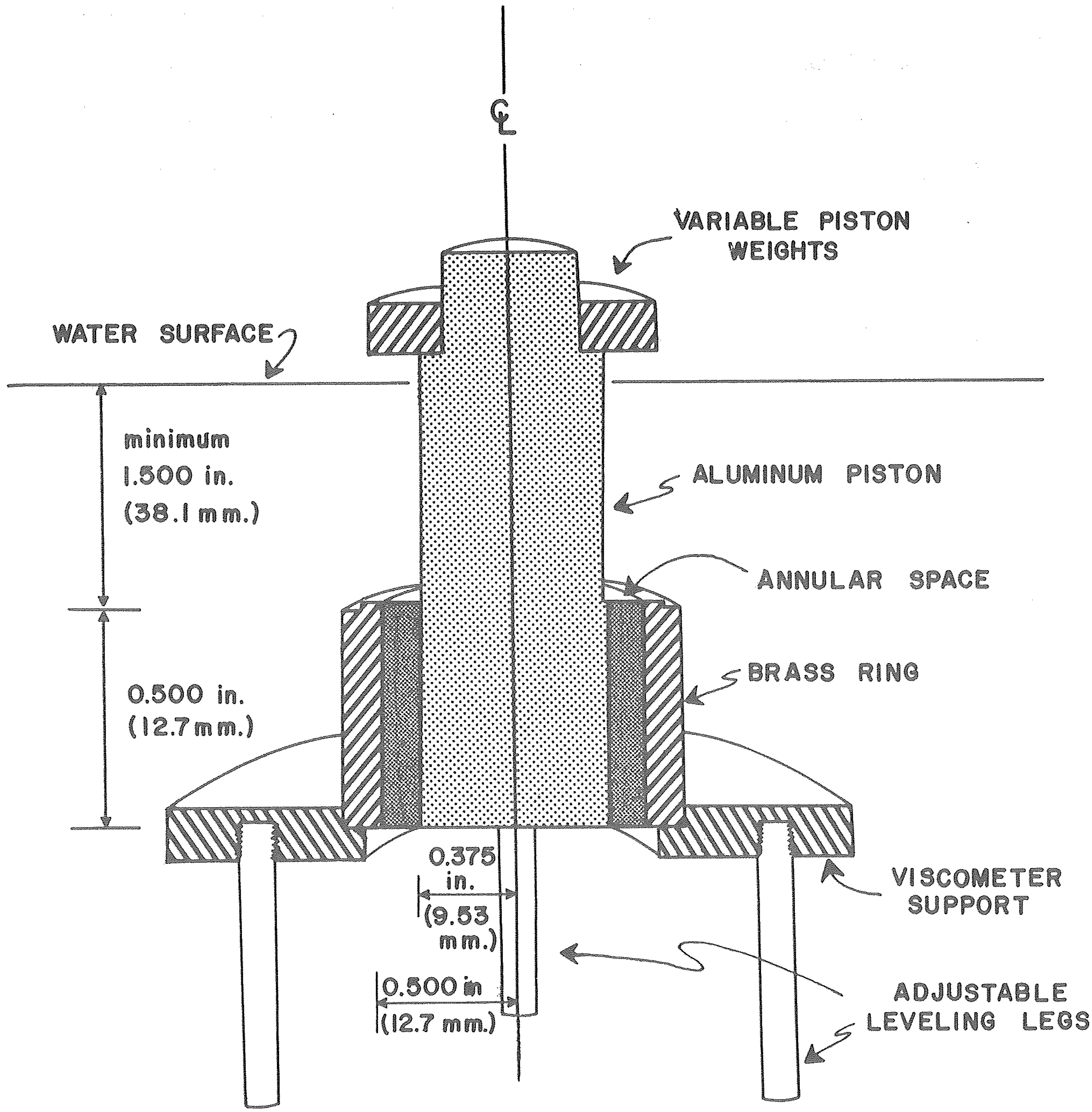


Figure 9. Slope Assembly for Barrett Slide Test



Note: All lines on plan view are circular

Figure 10. Falling Coaxial Viscometer

After several initial tests on the A-R, it was found that certain controlling elements in the viscometer design and operation were needed or recommended by Traxler and Schweyer (14) and included the following:

(1) The viscometer shall have an annular width to length ratio of less than 0.5.

(2) For accurate results, the displacement time of the falling piston shall not be less than 10 seconds.

(3) During the test, displacement of the piston shall not exceed 10 percent of the total length of the brass ring.

Due to the relatively low viscosity of plain asphalt at $104^{o}F$ ($40^{o}C$), it was difficult to accurately measure the rapid displacement of the piston. A viscometer built by R. A. Jimenez, University of Arizona, was used for these viscosity determinations. It consists of an extended ring length of two inches (50.8 mm) and an annular width of 1/4 inch (6.35 mm). As a comparison, the ring length used for all other falling coaxial testing was 1/2 inch (12.7 mm).

Equipment and Materials. The A-R mixes used in the viscosity determination were plain AR 1000; AR 1000/TP.044; AR 1000/TP.027 and AR 1000/TP.027-.044. The following apparatus was used in the viscosity determination test:

(1) Falling coaxial cylinder viscometer consisting of an outer brass ring, aluminum piston, aluminum centering ring and removable piston weights.

(2) Constant temperature water bath with thermostatic control, stirrer and thermometer.

(3) Telescopic sight with a vernier scale graduated in centimeters (cathetometer).

(4) Viscometer support (within water bath).

(5) Stop watches.

Procedure. A-R samples were mixed in accordance with previously described mixing procedures and immediately forced into the annular space of the falling coaxial viscometer. The various A-R mixes were tested at $59^{o}F$ ($15^{o}C$), $77^{o}F$ ($25^{o}C$) and $104^{o}F$ ($40^{o}C$) and repeated twice to compensate for experimental error. Generally, the viscosity test procedures are as follows:

(1) Set the desired water bath temperature and stirrer speed.

(2) Prepare the A-R mix or heat the plain asphalt to $250^{o}F$ ($122^{o}C$).

(3) Force the hot mix into the viscometer annular space making sure there are no voids. This can be accomplished by placing the ring and piston on a silicone grease-coated glass plate.

(4) Center the piston by utilizing the centering ring and allow the assembly to cool approximately 20 minutes. Trim off all excess material.

(5) Transfer the viscometer on the glass plate to the water bath and allow the sample to come to temperature for at least one hour.

(6) Remove the centering ring and glass plate carefully, and place the viscometer on the support within the water bath. The water level should be a minimum of 1.5 inches (38.1 mm) above the sample.

(7) Sight the telescope crosshairs a small distance below a well-defined mark on the piston. Start the stop watch when the piston mark coincides with the crosshair. Immediately move the telescopic sight down a distance of 0.1 cm. When the piston mark coincides with the crosshair, record time for a piston displacement of 0.1 cm. After three consecutive start and stop readings using 2 or 3 stop watches, recompress the piston and repeat the above procedure a minimum of three times using several different weights to vary the piston velocity and subsequent shear rate.

(8) For each weight used, plot the cumulative displacement vs. cumulative time. The velocity in cm/sec is calculated from the straight line portion

of the resulting plot. The shear rate S_r is calculated from the formula

$$S_r = \frac{V}{R-r} \tag{1}$$

where: V = piston velocity in cm/sec.

R = inner radius of brass ring in cm.

r = radius of piston in cm.

The shear stress is calculated from the equation

$$S_s = \frac{W \cdot g}{2\pi r L} \tag{2}$$

where: W = effective weight in grams (total weight minus the buoyant force)

g = 980 cm/sec^2, gravity acceleration

r = piston radius in cm.

L = length of brass ring in cm.

A plot of S_r vs. S_s is drawn on a log-log scale. The shear stress at a shear rate of 5×10^{-2} sec.$^{-1}$ is found from the resulting graph and the viscosity η is calculated from the following relation.

$$\eta = \frac{S_s}{S_R} \tag{3}$$

Field Installations

Experimental field installations were limited to A-R treatments on prepared subgrades in an attempt to provide additional information on waterproofing characteristics and physical degradation.

Three A-R field plots were installed at the outdoor exposure laboratory located at the Water Resources Research Center Field Laboratory, Tucson, Arizona. The outdoor exposure laboratory contained 21 plots of different lining materials that were continuously monitored. Each plot measured 8 ft. (2.44 m) by 16 ft.

(4.88 m) and was contained by a 4 inch (101.6 mm) high concrete curbing. The slope of all plots was 5% and all accumulated rainfall runoff was collected and measured to detect the effectiveness of each type of membrane. The plots used for A-R application were as follows:

Plot No. 13: Subgrade - silty sand type SM.
A-R application - AR 1000/TP.027-.044 applied at a rate of 0.5 gal/yd^2 (2.26 l/m^2).
Cover material - 3/8 inch (9.5 mm) washed stone applied at a rate of 25 lb/yd^2 (13.56 Kg/m^2).

Plot No. 14: Subgrade - silty sand type SM.
A-R application - AR 1000/TP.027-.044 applied at a rate of 0.5 gal/yd^2 (2.26 l/m^2).
Cover material - sand applied at a rate of 15 lb/yd^2 (8.14 Kg/m^2).

Plot No. 16: Subgrage - silty clay type CH.
A-R application - AR 1000/TP.027-.044 applied at a rate of 0.5 gal/yd^2 (2.26 l/m^2).
Cover material - none.

All field plots were continuously monitored since installation to obtain rainfall-runoff data and observed for any obvious weathering or physical deterioration.

The A-R membrane has been used on a 100,000 gal (3785 m^3) reservoir with interesting results. An application rate of 1.0 gal/yd^2 (4.53 l/m^2) was applied to a prepared subgrade that was primed with 0.5 gal/yd^2 (2.26 l/m^2) of SS-1h asphalt emulsion. The side slopes were 1:1 which is considered excessive for any type of lining material. Unwoven fiberglass (10 mil) was placed on the side slopes to help prevent downslope movement and compensate for poor subgrade conditions. Also, the entire membrane was coated with white acrylic roofing paint to reduce surface temperatures and subsequent flow. No earth cover material was used on the reservoir.

TEST RESULTS AND DISCUSSION

The following sections describe the results obtained from laboratory testing. Included are general discussions of relavent data as well as comparative graphical analyses.

Water Absorption Tests

The water absorbed by the asphalt-rubber is of little significance in most A-R applications. That is, the function performed by the A-R is not directly dependent on this property but rather on changes it might cause in other physical properties. For asphalts these changes are usually very minor in nature (9).

The water absorption test has two functions: first as an approximation as to the proportion of water absorbed by the A-R while submerged; and second, as a control test on the uniformity of the laboratory molded A-R specimens.

Tests on the A-R with kerosene were begun before the decision to eliminate kerosene mixes for testing waterproofing characteristics. The results for water absorption of a standard kerosene mix are included in this report as a matter of interest in comparison with the non-kerosene mixes.

Accurate dimensions of the specimens could not be obtained due to the plastic nature of the A-R membrane material. Many specimens deformed slightly upon handling during intermittent weighings and, therefore, could not be accurately measured for dimensional change during testing. It was also difficult to completely surface dry all specimens before periodic weighings due to surface irregularities of the A-R. Some human error, therefore, in the weighing procedures may be present.

The test specimens were cut from a molded membrane sample in the form of rectangular sections 3 in. (76.2 mm) long, 1 in. (25.4 mm) wide and 1/8 in. (3.2 mm) in thickness. A minimum of five specimens for each sample were placed in a container of distilled water at a temperature of 77°F (25°C). Due to the relatively little water absorption after 24 hours, long-term immersion testing was used to determine the water absorption with time. Graphs of results of water absorption vs. time are presented in Fig. 11. The lowest water absorption rate occurred with the AR 1000/TP.027-.044 mix. The maximum 28 day total absorption of 0.67%, however, was approximately the same as for the AR 1000/TP.044. Total water absorption for AR 1000/TP.027 was 0.8% for 28 day immersion. This higher absorption, although small, may be attributable to the fine particle size of rubber and thus greater absorptive surface area. It should be noted that in a modified CKE test using distilled water and crumb rubber, the total water absorbed by the rubber alone was exactly 1.0%. Although the AR 1000 asphalt by itself does not absorb a measurable amount of water, obviously the void phase in the A-R does.

Fig. 11 also shows the water absorption rate for AR 1000/TP.044 with 5% kerosene added to the mix. Rate of absorption as well as total absorption was nearly double for the kerosene mix. A reasonable explanation for this particular observation may be in the fact that kerosene and certain extendor oils cause a greater degree of swelling in the crumb rubber through selective absorption thus increasing the rubber surface area and or interstitial void space (12).

It is apparent that the maximum absorption for the A-R occurs within 14 to 21 days with little increase in weight after 28 days. This may only be a surface absorption phenomenon over a relatively short time span. Water immersion testing over months or years may yield slightly higher water absorption values. For the purposes of this study, it is safe to say that the maximum

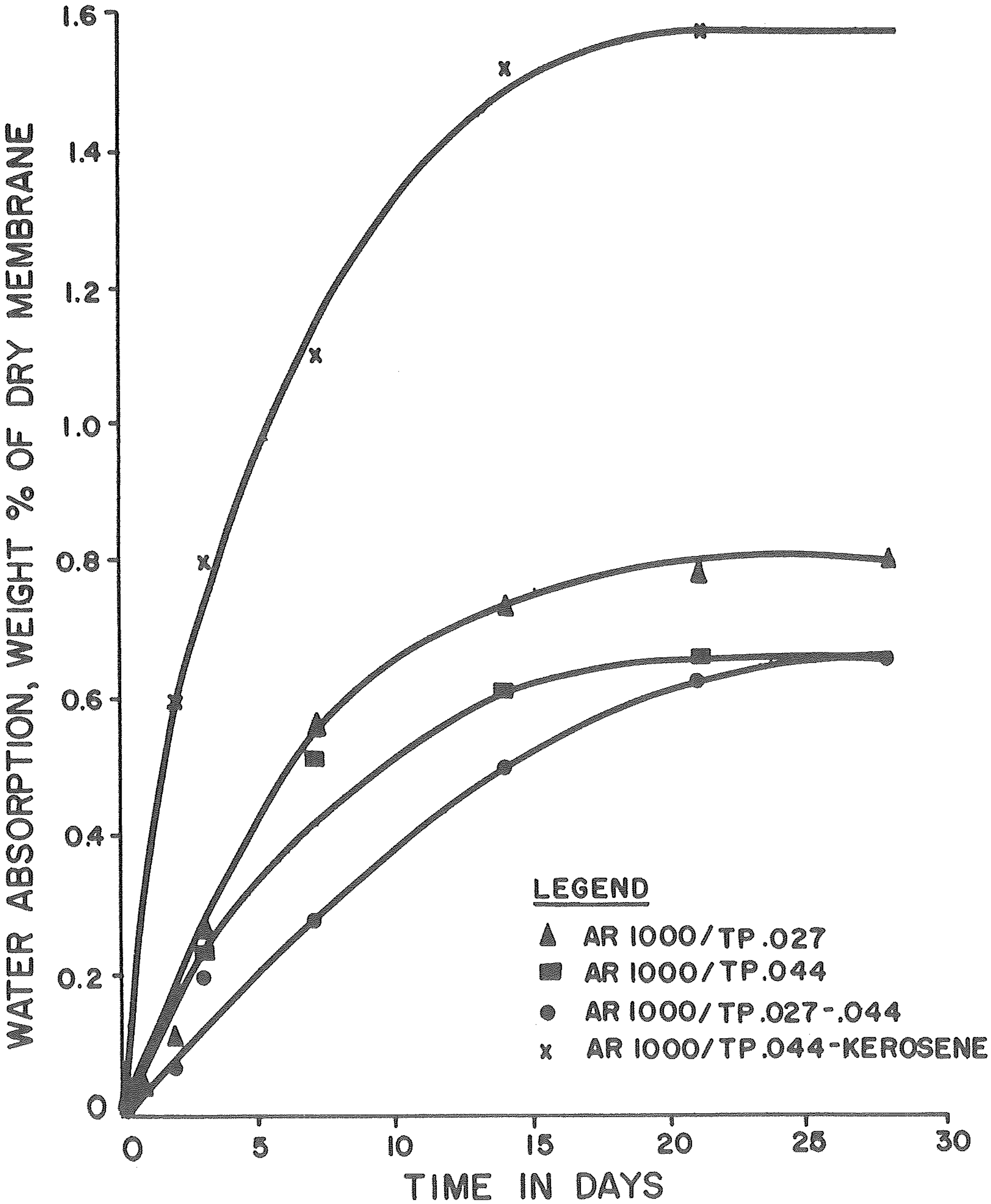


Figure 11. Water Absorption of the Asphalt-Rubber Membrane with Time

A-R water absorption is in the range of 0.6 to 0.8 percent by weight of the dry A-R membrane. Although additional testing may be needed, it is not felt there is any appreciable deterioration in the physical properties of A-R when totally immersed in water.

Water Vapor Transmission Testing

The water vapor transmission (WVT) test was patterned after ASTM E96-72 Procedure BW, which tests one wetted surface only for films not under a hydraulic head. This test was used in an attempt to determine the approximate permeability of various combinations of A-R mixes. It should be noted that the passage of water vapor and other gases through pure asphalt films is in most instances by molecular diffusion and therefore very small (9). Filler materials, however, have been known to change the permeability of asphalt. Crumb rubber, when added to asphalt at the relatively high percentage rate (by weight of total mix) of 25, produces a rubber-aggregate system that undoubtedly contains void spaces and possible microscopic channels that will transmit moisture.

The WVT devices were weighed periodically to determine the relative weight loss as water vapor escaped. The successive weight loss vs. elapsed time are plotted to give a straight line representing rate of water vapor transmission. It is interesting to note that AR 1000 asphalt alone could not be tested due to its relatively low viscosity at the ambient test temperature of 77^{o}F (25^{o}C) and subsequent high susceptibility to flow even through the retaining screen.

A total of 57 WVT test assemblies were fabricated and tested for a minimum of 30 days each. Due to the nature of the A-R, a number of specimens failed before the 30 day test period ended making it necessary to substitute new specimens. A minimum of three specimens of each A-R mix combination were tested and the resulting data averaged to produce relatively reliable WVT rates.

Figures 12 through 14 represent the relative WVT rates for the various mixes and membrane thicknesses. Accurate WVT slopes were obtained by applying a least squares linear regression to the accumulated data of weight loss vs. time. All three graphs illustrate the variability in WVT rates with membrane thickness, eg. the 0.5 gal/yd^2 (2.26 l/m^2) membrane transmits water vapor at a faster rate than either the 0.75 gal/yd^2 (3.40 l/m^2) or 1.00 gal/yd^2 (4.53 l/m^2) membrane thicknesses.

During the first 3 to 5 days of testing the WVT rate tends to be more rapid. After that time, the flow rate becomes linear as shown by the straight line portion of the graphs in Fig. 12 through 14. The only exception is for the 0.75 gal/yd^2 (3.40 l/m^2) membrane in Fig. 12 in which the WVT rate apparently decreases with time.

If the WVT rate for the three thicknesses of each mix were averaged, the least permeable mix would be the AR 1000/TP.027 (2.57 gms/m^2-24 hr) followed by the AR 1000/TP.027-.044 (2.87 gms/m^2-24 hr) and AR 1000/TP.044 (3.11 gms/m^2-24 hr). These results generally follow the hypothesis that the finer rubber particle size distribution forms a closer packed mix resulting in better membrane impermeability.

Figure 15 illustrates the overall WVT rates for the various thicknesses and A-R combinations. Note that the WVT rates are relatively close in numerical value. Table 1, Appendix B, summarizes the WVT rates and some corresponding permeability constants that are in common usage in the literature. Coefficient of permeability (K) for the A-R was determined by utilizing Darcy's Law for one-dimensional flow across a membrane:

$$Q = k\frac{H_w}{d} At \tag{4}$$

solving

$$k = \frac{Q_d}{AH_w t} \tag{5}$$

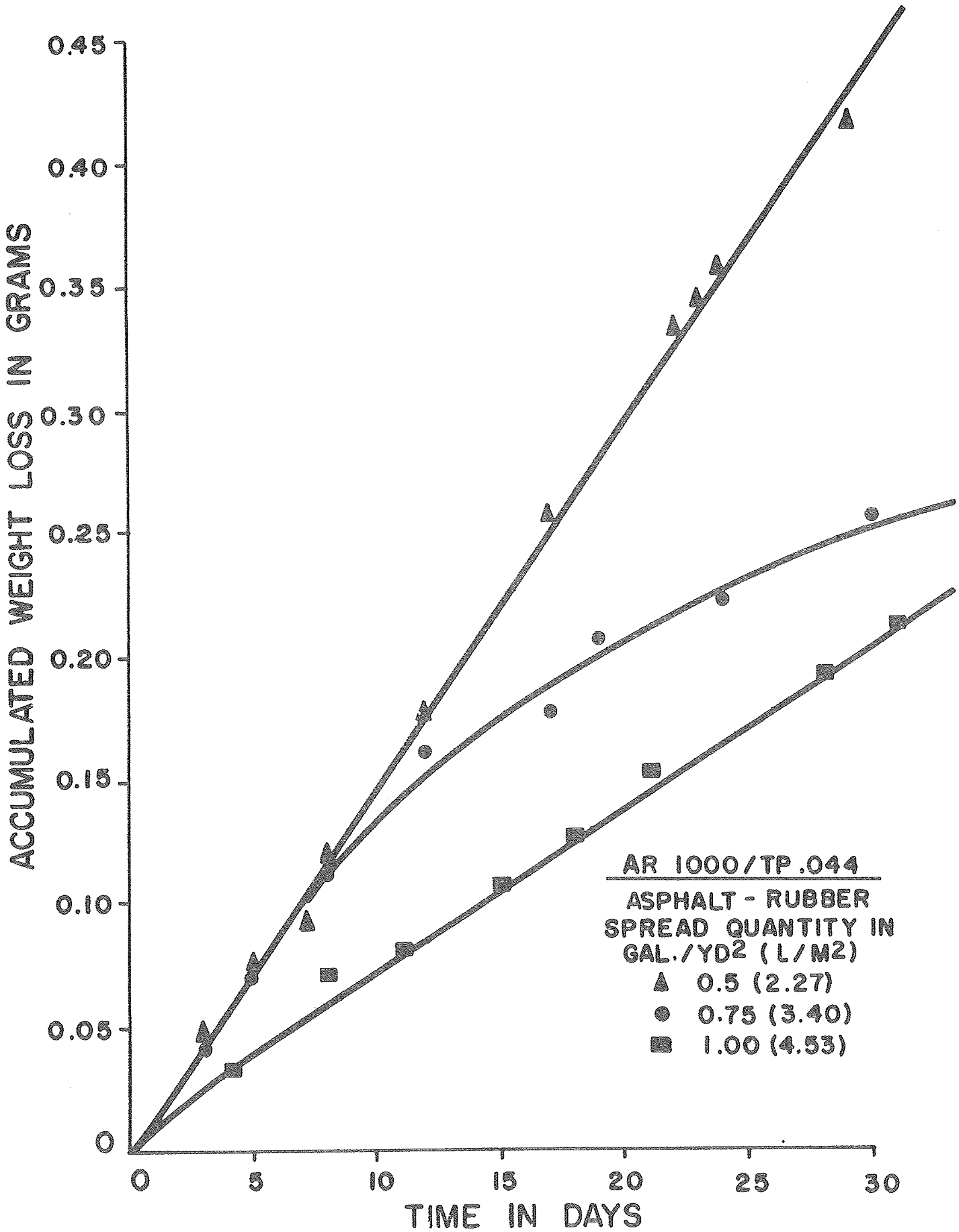


Figure 12. WVT - Accumulated Weight Loss Vs. Time for AR 1000/TP.044

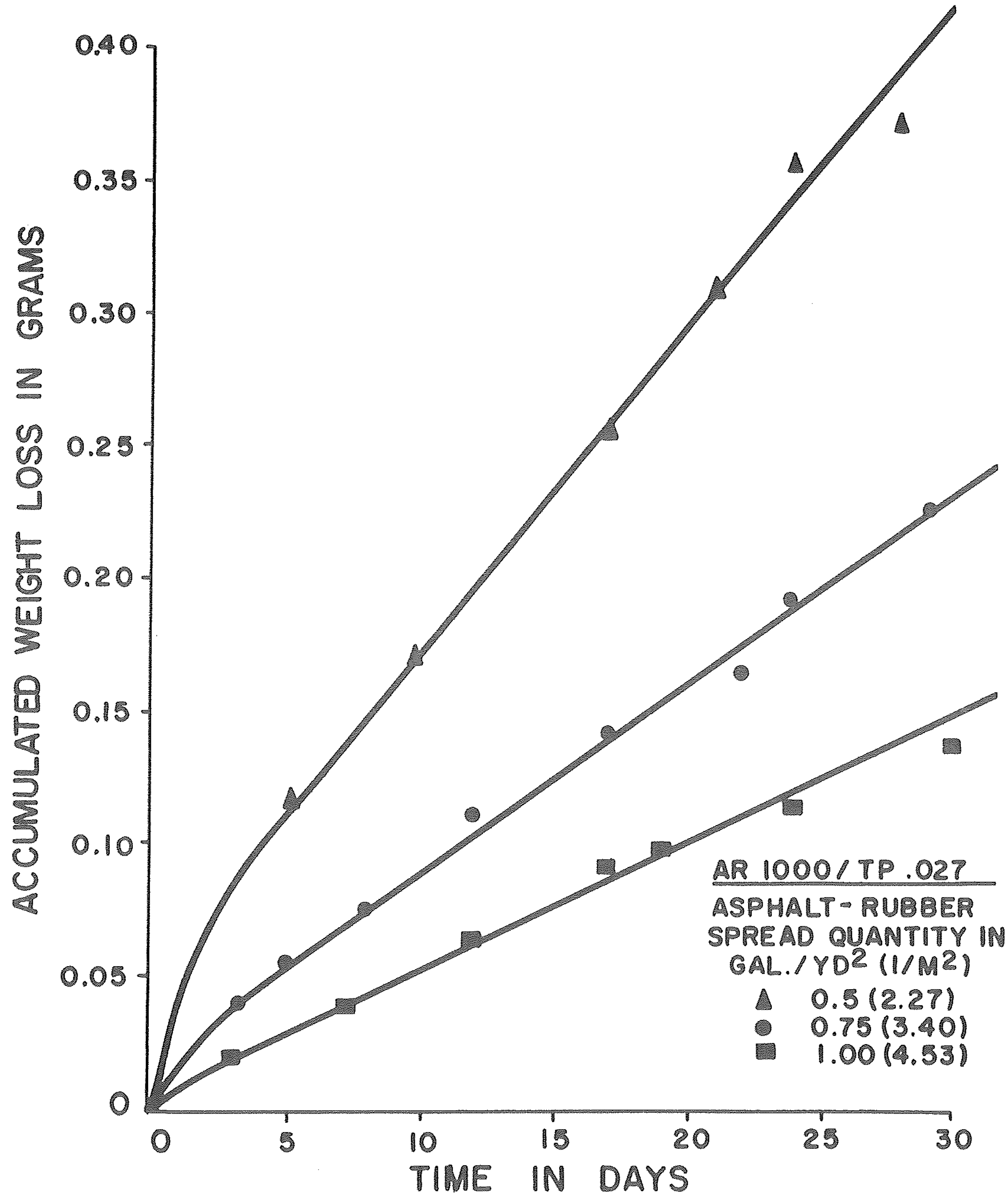


Figure 13. WVT - Accumulated Weight Loss Vs. Time for AR 1000/TP.027

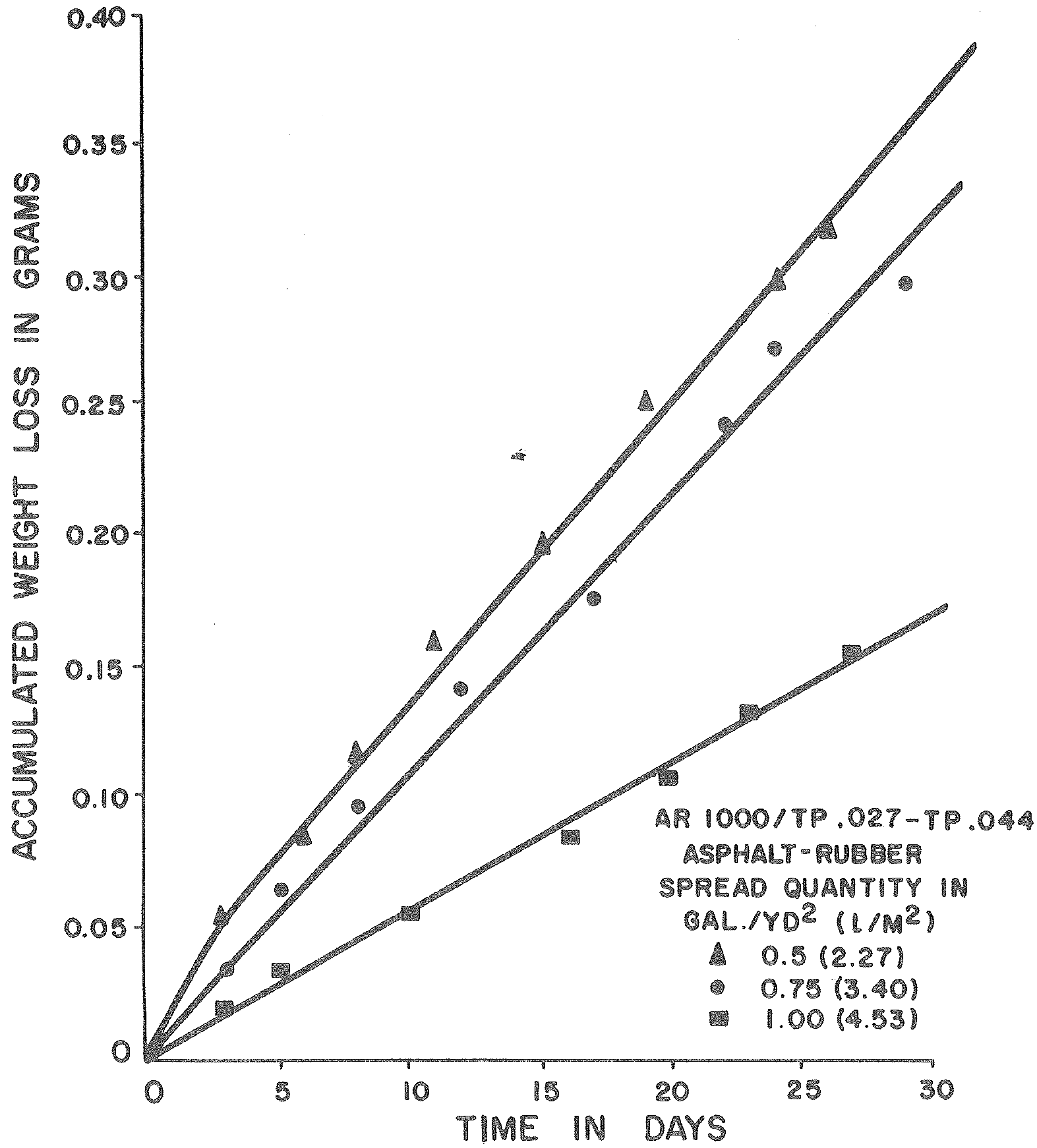


Figure 14. WVT - Accumulated Weight Loss Vs. Time for AR 1000/TP.027-044

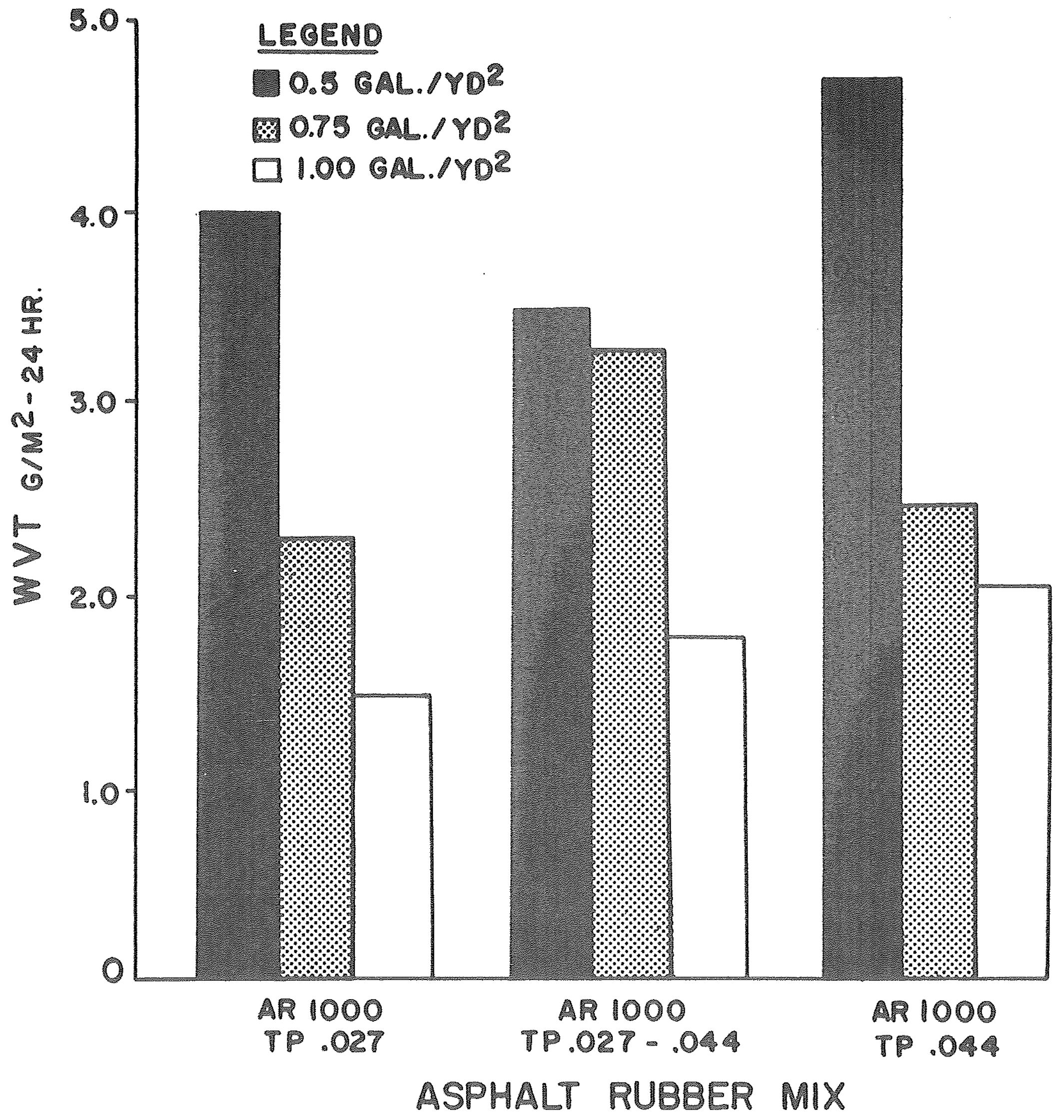


Figure 15. Water Vapor Transmission Rate for Various A-R Combinations

where k = coefficient of permeability (cm/sec)

Q = flow through membrane in cc (WVT Tests)

d = membrane thickness in cm

A = cross sectional area of sample (cm^2)

H_w = Hydrostatic head (cm of water)

t = time (sec)

Depending on the membrane thickness and mix, k varied from a low value of 2.14×10^{-12} cm/sec to a high of 3.73×10^{-12} cm/sec. These values, for all practical purposes, can be considered as impermeable. Also given in Table 1, Appendix B, are the permeability constant for the various mix combinations and another unit of permeability called the perm. The perm has gained wide acceptance in the construction material industry and in the American Society for Testing Materials. According to Hoiberg (9), a typical oxidized asphalt possesses a permeability of 0.0171-0.0330 perms which is slightly higher than the range of laboratory values for the asphalt-rubber as shown in Table 1 (0.008-0.028 perms). This may indicate that the rubber aggregate has no appreciable detrimental effect on the overall permeability of an asphalt membrane, at least under controlled laboratory testing conditions.

Permeability Testing

Permeability testing was included in this test program as a possible check on the permeability data obtained from water vapor transmission testing.

In general, a specimen was placed in the permeameter with a constant hydrostatic head applied to one end. Flow through the A-R membrane was measured as it escaped through the porous stone and base plate (refer to Fig. 4 of Test Methods). The coefficient of permeability k, in cm/sec can be calculated from Darcy's equation assuming the A-R to be porous. WVT testing showed the A-R to be relatively impermeable, however permeameter testing indicated fairly low coefficients of permeability ranging from 2.01×10^{-6} cm/sec to 9.62×10^{-7} cm/sec. Upon close inspection of individual test specimens, it was discovered that most failures occurred at the porous stone/aluminum base interface or were due to cutting of the specimen with the "O" ring because of over tightening between the top plate and base plate. Several attempts at sealing the interface failed. The best seal was obtained with a hard wax which resulted in several specimens not showing any visible flow rate. Due to the difficulty in obtaining an adequate edge seal, and the fact that in the liquid phase (as opposed to water vapor phase) it is very difficult to obtain accurate flow rate, it is felt that the permeameter test results were unreliable for presentation. The WVT test results, therefore, should be used as relative permeability data for the various A-R mixes.

There were no permeability readings when testing plain AR 1000 asphalt specimens if tested continuously for less than 48 hours. However, after 48 hours, it was noted that the plain asphalt flowed through and around the porous carborundum stone and into the permeameter tubing. This occurred under 5 psi (34.5 KN/m^2) hydrostatic pressure. The asphalt-rubber mixes did not penetrate the stone even after 72 hours of testing under as much as 15 psi (103.5 KN/m^2) static head. This is a further indication of the greatly improved resistance to flow when crumb rubber was added to the asphalt. The A-R combination behaves much the same as a tough, homogeneous membrane in that it greatly resists deformation and/or flow compared to that of plain asphalt.

Although the actual permeameter data were not used for comparative analysis, the results of the tests that were run are shown in Table 3, Appendix B.

Ductility Testing

The ductility of the base asphalt or A-R material was measured by the distance in centimeters to which it elongated before breaking when the two ends of a standard briquette (ASTM D113-74) were pulled apart at a specified speed and test temperature. The standard test speed of 5 cm/min was used at a test temperature of 77°F (25°C).

Table 7, Appendix B, gives the ductility test results for asphalt and A-R specimens tested in conjunction with this study. Note that the ductility of the base asphalt (AR 1000) is greatly reduced when the vulcanized crumb rubber is added as shown in Fig. 16. This indicates an obvious reduction in flow characteristics when asphalt cement and crumb rubber are combined in the A-R mix. This mix may be thought of as an aggregate mix (the rubber being the aggregate). Although the exact amount of rubber that disperses in asphalt has not yet been determined, it is apparent that the finer rubber aggregate disperses more in the asphalt than the coarse. This is reflected in a higher elasticity with resulting higher ductility values. The elastic quality of this mixture may be the mechanical action of the undissolved rubber particles performing as an interlocked matrix of completely elastic aggregate (13).

In varying the particle size distribution (aggregate gradation) of the crumb rubber, it was found that the smaller particle size exhibited a greater degree of ductility than the coarser particle size (see Fig. 16). This would further indicate a reduction in flow characteristics as the rubber particle size is increased. The ductility results for the A-R material are well above the minimum allowable ductility requirements for asphalt in hydraulic structures which is 3.5^{+} cm (2).

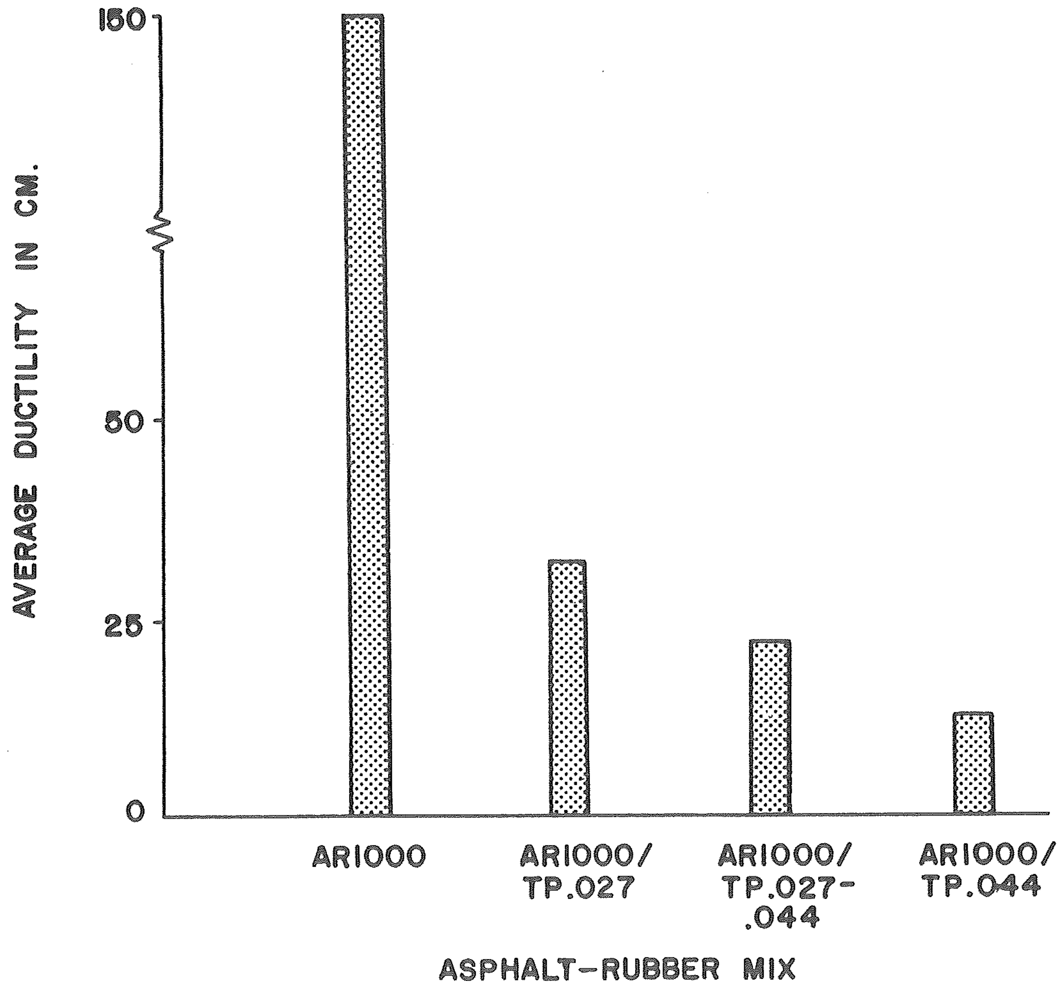


Figure 16. Average Ductility for Various A-R Mixes

Toughness/Tensile Pullout Test

As an integral part of the tensile testing phase of the A-R mixes, an attempt was made at utilizing a test procedure originally designed to test rubberized asphalt employing liquid latex or powdered rubber. Toughness was defined as the resistance a material such as asphalt or asphalt-rubber offers to deformation and measured as the work required to extract a steel hemisphere from the asphalt or asphalt-rubber at a predetermined rate of pull and temperature (6,8).

The above test is somewhat arbitrary so we propose the use of the term relative toughness which is calculated by obtaining the area below the force-deformation curve resulting from the test. Typical force-deformation curves for asphalt and asphalt-rubber are shown on Fig. 17.

An examination of the asphalt-rubber curve (17b) indicates two distinct rates of force vs. deformation; these are sections ab and bc shown on the diagram. Rate ab relates to the work required to pull the half-ball out of the mix while it adheres to the hemispherical surface. At b the mix begins to break away from the bottom of the hemisphere leaving a circumferential area free of asphalt-rubber. The work required to pull the half-ball free from the asphalt-rubber is related to line bc and reflects the loss of bond with the asphalt-rubber. At point c total separation takes place. The area abcd represents the total work (relative toughness) required to pull the hemisphere free of the asphalt-rubber.

As a comparison, Fig. 17a shows the force-deformation relationship for the AR 1000 asphalt. The shape of this curve is similar to that for latex rubberized asphalt as presented by Benson (5). Note that the AR 1000 extends a great deal farther than the asphalt-rubber; additionally, fracture occurs within the asphalt and not at the asphalt-steel interface. This difference in extensibility was noted in the ductility test.

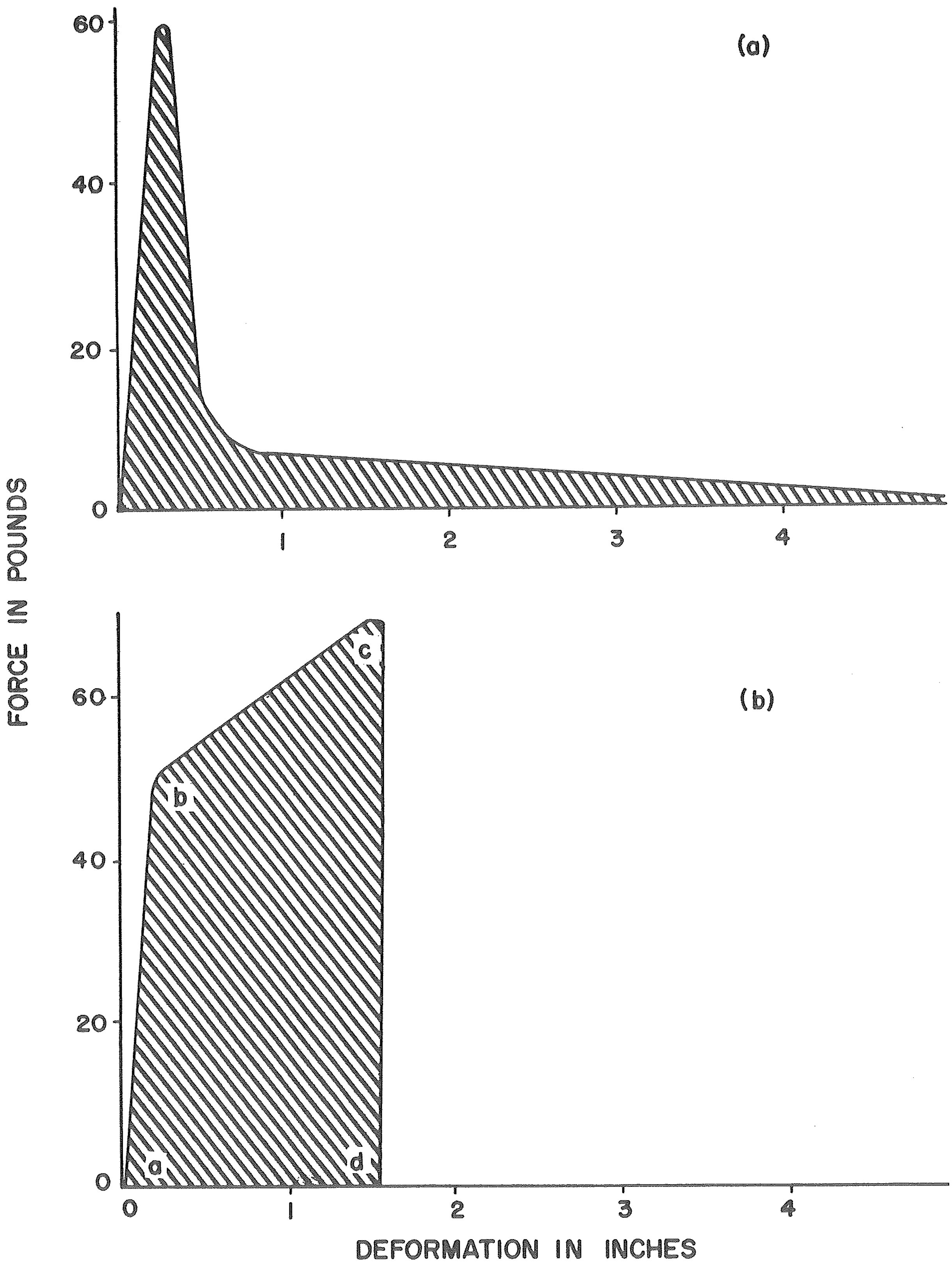


Figure 17. Typical Stress-Strain Curves for (a) Asphalt Cement and (b) Asphalt-Crumb Rubber

The effect of changing the gradation of the rubber particles on relative toughness is shown in Fig. 18. As shown in the figure, the coarser the gradation, the greater the value of relative toughness. The finer particle size of rubber mixture had a value of relative toughness approaching that for plain asphalt. The effect of gradation of rubber on relative toughness corresponds to gradation effects on ductility value, i.e., higher ductility value for the fine rubber mixture and lower for the coarse rubber particles. In general, the amount of increase in relative toughness after adding the rubber was 247% for TP.027, 346% for TP.027/TP.044, and 387% for TP.044.

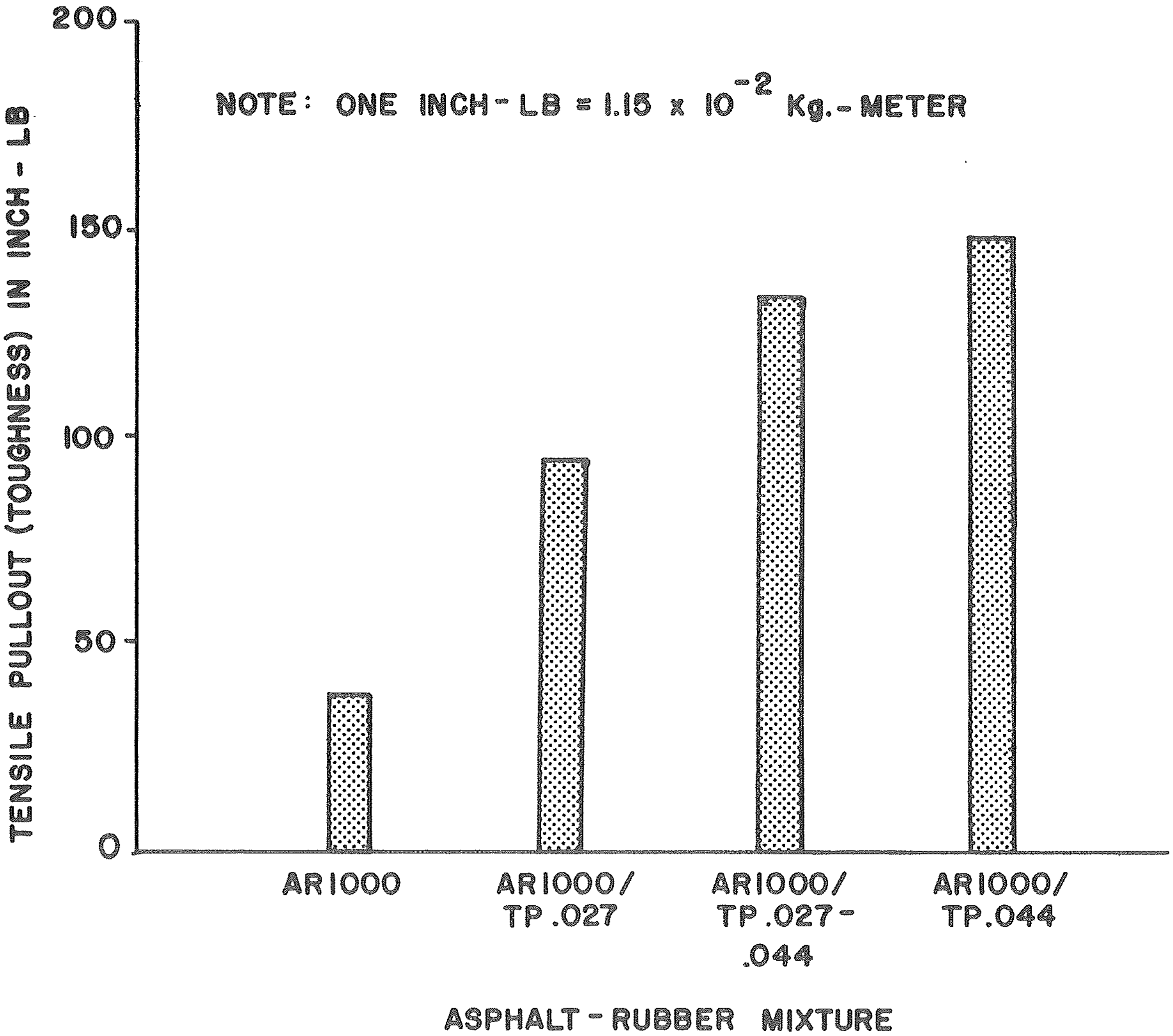


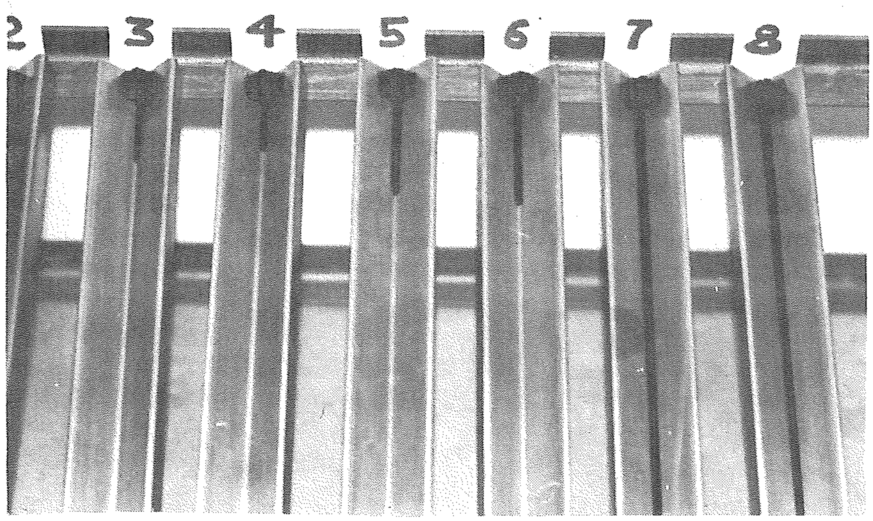
Figure 18. Toughness Values for Various A-R Mixes Tested at 77°F (25°C)

Modified Barrett Slide Test

As outlined in the Test Methods section, an attempt was made at determining the relative flow/slope stability characteristics of the A-R mixes. The A-R did not behave as anticipated, however, in that the total test cube remained intact at the top of the slope but exhibited asphalt separation and subsequent flow. It was anticipated that the A-R would react similarly to a filled asphalt cement and flow as a homogeneous mix.

The various A-R mixes tested were molded into 1/2 inch (12.7 mm) cubes. The individual cubes (in replicate) were placed in a copper slide at a 1-1/2 to 1 slope and held for 48 hours at 140^{0}F (60^{0} C). The length of run down the slope of a particular A-R cube may be taken as a measure of the flow retarding efficiency of the rubber particle size involved (7).

Figure 19 shows the relative slope movements of the asphalt contained in the various A-R mixes. Slides 1 and 2 (not shown in Fig. 19) contain AR 1000 without rubber, which flowed the entire slide length within six hours from start of testing. Slide 3 and 4 contain AR 1000/TP.027. Note that the A-R cubes remain intact after 48 hours at 140^{0}F (60^{0} C) and that only the asphalt separates and flows downslope. As the rubber particle size in the mix becomes larger, more asphalt tends to separate out. This is an indication that the greater amount of crumb rubber aggregate surface area (smaller particle size) the more homogeneous the mix becomes due to increased surface interaction. This further indicates that the finer rubber aggregates disperse more in asphalt. The coarse crumb rubber particle size (slide 7 and 8, Fig. 19) shows a much greater degree of asphalt separation due to less rubber surface area and more intersticial void spaces. This would indicate that A-R with the coarse (TP.044) rubber particle size would be less desirable on slope application due to asphalt



Slide 3 and 4 - AR 1000/TP.027
Slide 5 and 6 - AR 1000/TP.027-.044
Slide 7 and 8 - AR 1000/TP.044

Figure 19. Relative Asphalt Separation and Flow for Various A-R Mixes Using the Barrett Slide Test.

separation and flow at higher surface temperatures. The 50/50 mix of TP.027 and TP.044 (slide 5 and 6, Fig. 19) indicated a substantial reduction in asphalt separation and flow due to the increased rubber contact surface area.

Upon aging the various mixes, there was no appreciable difference in total amount of asphalt separation when comparing 1-day, 7-day and 30-day slope tests.

The efficiency of various aggregate rubber sizes used as stiffening agents will vary with the type, source, particle size gradation and subsequent surface area of the crumb rubber. A summary of the slide test data is presented in Table 5, Appendix B.

Viscosity Testing

The falling coaxial viscometer was used as a viable means of measuring the relative viscosities of A-R mixes when varying the rubber particle size distribution and temperature. In particular, the viscosity determination was used to measure the relative consistency of the material and characterize it so that its flow behavior (rheology) and performance can be controlled and predicted. The temperatures used in this study more closely reflect in place service of the material rather than the flow characteristics in the range of temperatures used during application.

The A-R mix is essentially a thermo-plastic material; that is, the material changes its physical characteristics with temperature. This variation with temperature is an important consideration for the A-R, particularly when considering in-place performance such as slope stability. A common technique used to study the change in viscosity with change in temperature (temperature susceptibility) is to specify the slope of the temperature vs. viscosity relationship. A straight line relationship is obtained when the viscosity (log-log scale) and the temperature (log absolute) are plotted graphically.

The viscosity test results are presented in Table 6, Appendix B. Upon analyzing the results, it was found that the crumb rubber (aggregate), when used in conjunction with a base asphalt, substantially increased the relative viscosity of the total mix over that of plain asphalt for the test temperatures. Also, when the rubber particle size distribution was varied in the A-R mix, the viscosity was substantially changed. In particular, the larger the particle size (less interactive surface area) the higher the viscosity. As the particle size became finer, the viscosity approached that of the base asphalt. This may again represent the phenomenon that the finer rubber aggregate more readily disperses with more of the base asphalt thus reducing the aggregate system to a more homogeneous mix of lower viscosity.

Figure 20 represents the viscosity-temperature relationship (temperature susceptibility) for the base asphalt and A-R mixes. The slope of each line is a relative measure of the temperature susceptibility of each A-R mix as compared to the base asphalt. Note that slopes of the A-R mixes are approximately equal to each other whereas the slope for the base asphalt is much greater. Generally, the steeper the slope, the more temperature susceptible is the material. In particular, when crumb rubber is added to asphalt, the resulting mixture has a lower temperature susceptibility than the base asphalt.

Field Installations

After approximately one year of exposure, the following observations on the A-R plots were made:

Plots No. 13 and 14: Accumulated rainfall-runoff data indicate that both plots shed in excess of 95% of measurable precipitation indicating outstanding waterproofing characteristics. There are no signs of any significant physical

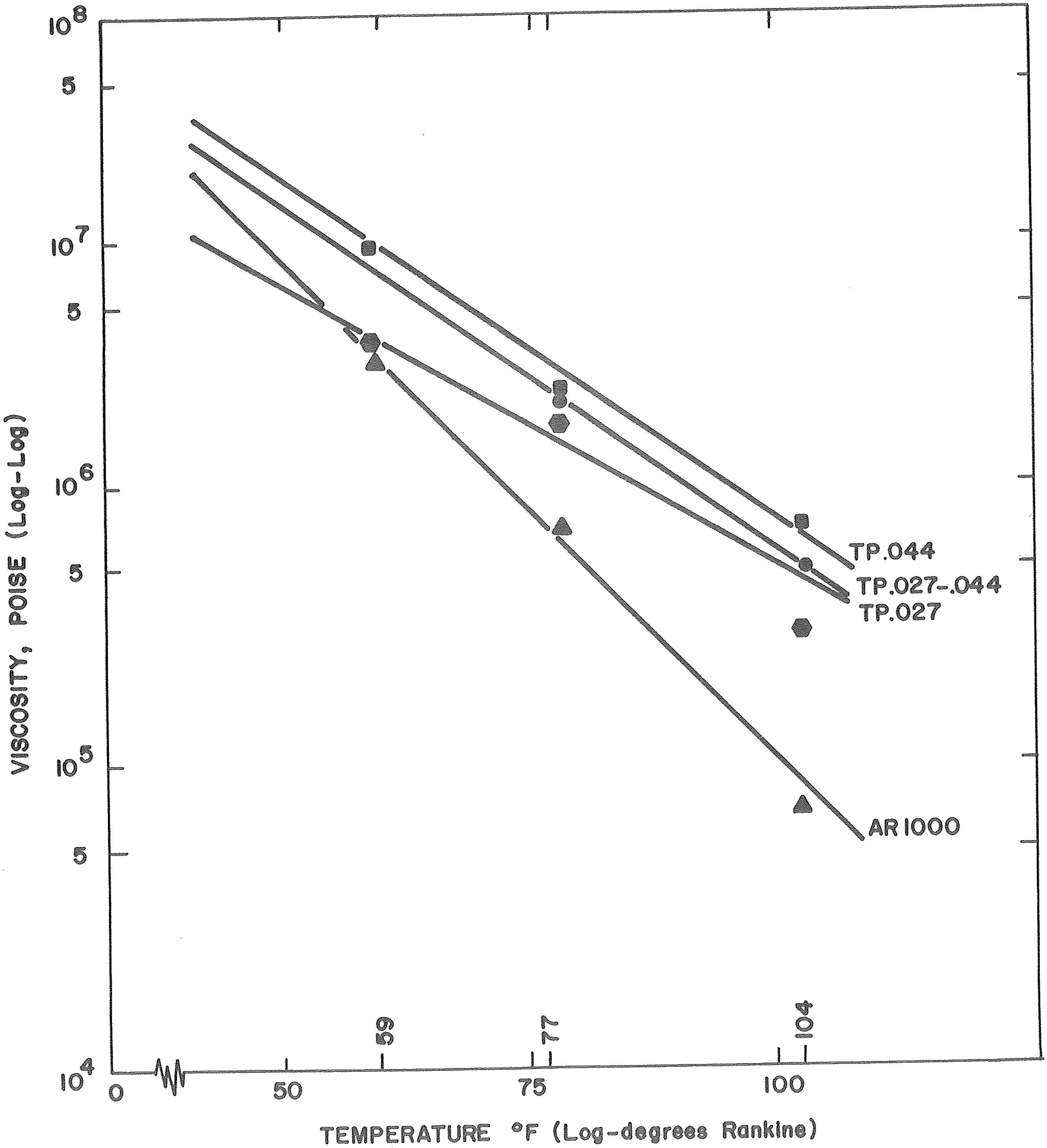


Figure 20. Viscosity-Temperature Relationship for Asphalt and Asphalt-Rubber Mixes

deterioration of the membrane material. However, some of the sand cover on plot 14 has eroded and accumulated at the base of the plot.

Plot No. 16: The A-R membrane has deteriorated slightly due to the highly expansive subgrade and exposed condition. The expansive clay has caused the A-R to crack with the subgrade. It should be noted that the cracks do reheal themselves on hot days. Also, some atmospheric degradation has been noted because of the lack of cover material. Due to the cracking, the rainfall-runoff efficiency was less than 40%.

The A-R membrane that was installed on a 100,000 gal (3785 m^3) reservoir has exhibited excellent physical and waterproofing characteristics. The A-R material exhibited minimal downslope movement and no separation due to the unwoven fiberglass reinforcement and the relatively homogeneous A-R mix. The white acrylic paint also prevented any material flow by keeping surface temperatures down to a minimum. There was very little loss of water from the reservoir due to seepage which indicates that the A-R forms an effective seepage barrier, even under adverse subgrade conditions.

SUMMARY AND CONCLUSIONS

The following is a summary of findings and conclusions reached within the scope of and restricted to this study.

1. The asphalt-rubber, as a membrane, absorbs a relatively insignificant amount of water. The finer particle size of rubber in the A-R mix absorbs slightly more water than the coarser particle size. It is apparent that the addition of rubber to asphalt does increase the water absorption over that of a plain asphalt membrane.
2. The degree of water vapor transmission of the A-R membrane is inversely proportional to the membrane thickness, e.g., lower WVT rate for the thicker membrane. The permeability of any of the A-R mix or thickness combinations was low enough that for all practical purposes, the A-R can be considered as impermeable. The rubber aggregate has no appreciable detrimental effect on the overall permeability of the A-R membrane.
3. Generally, the addition of rubber to asphalt greatly decreases the ductility value over that of the base asphalt. The finer rubber aggregate mix exhibits a higher value of ductility than the coarser rubber aggregate mixes.
4. The toughness (resistance to deformation) of the A-R mix increases as the rubber aggregate particle size is increased. This is further illustrated with the decrease in elasticity (decrease in ductility value) of the A-R mix with increase in rubber particle size. The rubber aggregate significantly increases the toughness of the mix over that of the base asphalt.

5. As rubber aggregate is added to asphalt, the resulting mix has greatly reduced flow or downslope movement over that of the base asphalt. The flow retarding efficiency of the rubber is obvious. As the rubber particle size decreases, more rubber is dispersed in the asphalt (more rubber surface area) and subsequently reduces the amount of asphalt that can separate from the total A-R mix. A coarser particle size in the A-R mix will result in more asphalt separation if placed on a relatively steep slope.
6. The relative viscosity of asphalt is significantly increased with the addition of crumb rubber. Also, the larger the particle size, the higher the viscosity. The temperature susceptibility of the A-R mix is much less than that of plain asphalt.
7. Observations of a limited number of field installations indicate that the A-R as a membrane material exhibits excellent waterproofing characteristics. Adequate subgrade preparation is of prime importance when considering the overall effectiveness of the A-R membrane.

Within the scope of this study, asphalt-rubber as a membrane material exhibits excellent waterproofing properties. It is a tough, relatively homogeneous mixture in which the addition of rubber aggregate increased the elastic and viscous components with which asphalt resists deformation. The lower temperature susceptibility of the A-R and the flow retarding efficiency of the rubber aggregate make it more desirable for use on slopes. In addition, the A-R mix would result in greater impact strength, improved stability and better adhesive characteristics over that of the base asphalt.

It should be noted that A-R combinations are infinite. Different types of asphalt are affected by different types of rubber, rubber particle size, and total amount of rubber used in given mix. Also, properties are affected by mixing procedures and site conditions. Extensive, additional testing and A-R field performance data are needed before comprehensive specifications can be formulated for A-R use in the construction industry.

REFERENCES

1. Asphalt Institute, "Mix Design Methods for Asphalt Concrete and Other Hot Mix Types," Manual Series No. 2, 4th Edition, March, 1974.

2. Asphalt Institute, "Asphalt in Hydraulic Structures," Manual Series No. 12, 5th Edition, 1965.

3. ASTM Designation D570, Part 35, American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennyslvania, 1972.

4. ASTM Designation E96, Part 35, American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania, 1972.

5. ASTM Designation D113, Part 15, American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pennsylvania, 1974.

6. Benson, Jewell R., "Tentative Standard Method of Test for Toughness and Tenacity of Rubberized Asphalts," Denver, Colorado, 19755.

7. Ellsperman, L. M. and Becker, C. J., "Membrane Flow Characteristics and Application Conditions for Filled Asphalt Cement Used in Prime-Membrane Type Canal Lining," U. S. Bureau of Reclamation, Bituminous Laboratory, Report No. B-8, 1947.

8. Endres, H. A., "Latest Developments in Rubberized Asphalt," Reprint from University of Pacific Bulletin, Vol. 48, No. 8, 1966.

9. Hoiberg, Arnold J., "Bituminous Materials: Asphalts, Tars and Pitches," Volume II, Part I, Interscience Publishers, New York, 1965.

10. LaGrone, B. D. and Huff, B. J., "Use of Waste Rubber in Asphalt Paving," U. S. Rubber Reclaiming Co., Inc., Vicksburg, Mississippi, 1973.

11. Morris, Gene R., "Asphalt-Rubber Membranes: Development, Use, Potential," Arizona Department of Transportation, Phoenix, Arizona, 1975.

12. Morris, Gene R., and McDonald, C. H., "Asphalt-Rubber Stress Absorbing Membranes: Field Performance and State-of-The-Art," Arizona Department of Transportation, Phoenix, Arizona, 1975.

13. Olsen, Robert E., "Rubber-Asphalt Binder for Seal Coat Construction," Implementation Package 73-1, Federal Highway Administration, U. S. Department of Transportation, Washington, D.C., 1973.

14. Traxler, R. N., and Schweyer, H. E., "Measurement of High Viscosity: A Rapid Method," Proceedings, American Society for Testing and Materials, Vol. 36, Part II, 1936.

15. Welborn, J. York, and Babashak, J. F., "A New Rubberized Asphalt for Roads," Journal of the Highway Division, Proceedings of the American Society of Civil Engineers, Vol. 84, No. HW2, April, 1958.

APPENDIX A

LABORATORY MATERIAL SPECIFICATIONS

APPENDIX A

LABORATORY MATERIAL SPECIFICATIONS

Asphalt Cement

Grade: AR 1000
Supplied by: Arizona Department of Transportation, Phoenix, Arizona

Viscosity, Kinematic at 275^{o}F	167 CS
Viscosity, Absolute at 140^{o}F, 30 cm hg vac.	1410 Poises
Penetration, 100 gm, 5 sec., 77^{o}F	120
Flash Point	455^{o}F (235^{o}C)
Tests on Residue from Thin Film Oven Test;	
Penetration, 100 gm., 5 sec., 77^{o}F	78
Penetration, % of original	65%

Rubber

Ground vulcanized tire rubber supplied by the Arizona Department of Transportation, Phoenix, Arizona. The specific gravity of the material shall be 1.17±0.03 and shall contain no more than a trace of fabric and shall be free of wire or other contaminating materials. The granulated rubber shall be fully vulcanized.

The particle size distribution of the granulated rubber used in this study is shown in Fig. 1A.

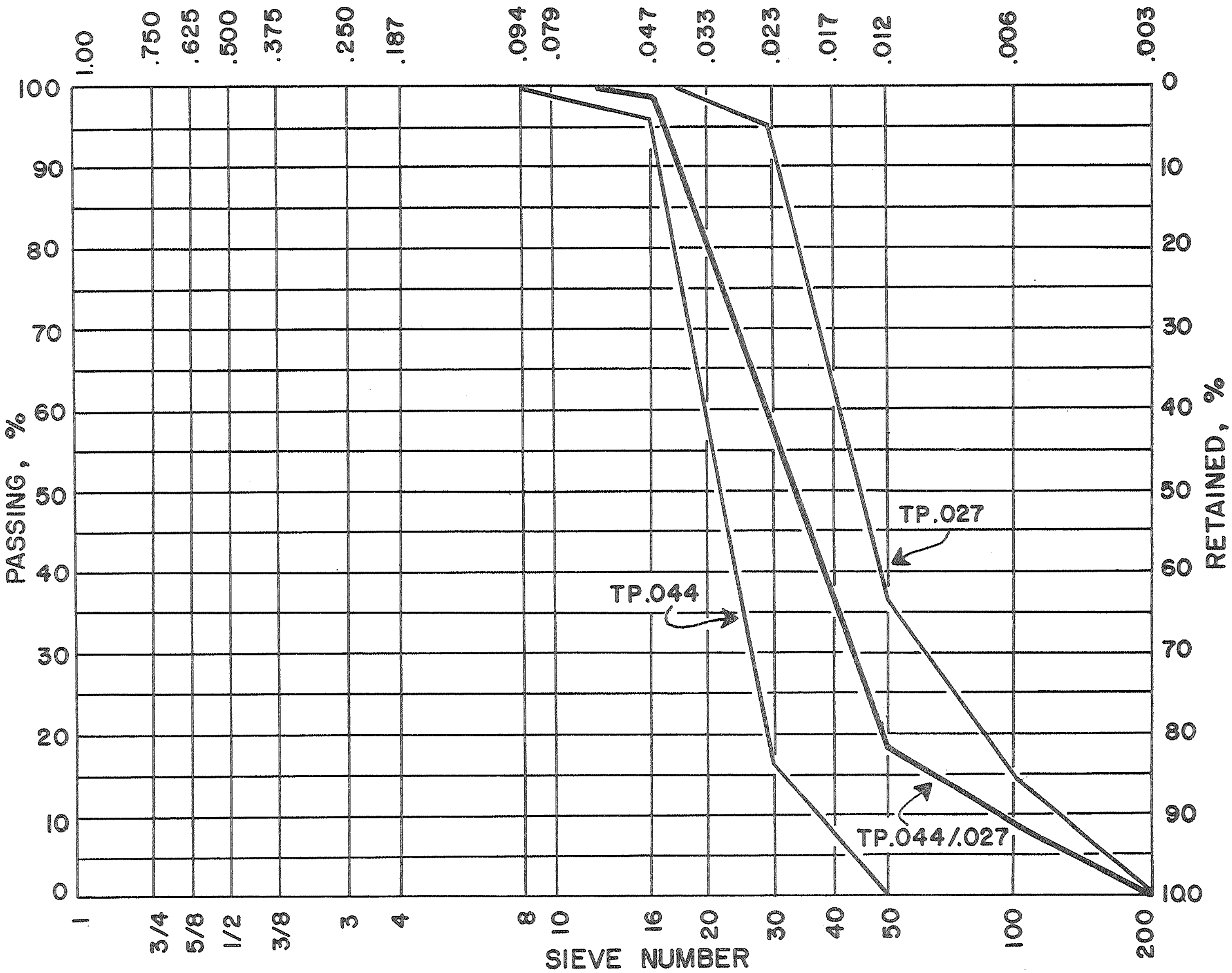


Figure 1A. Particle Size Distribution of Crumb Rubber Used in A-R Testing

APPENDIX B

RESEARCH DATA AND TEST RESULTS

TABLE 1

WATER ABSORPTION TEST RESULTS FOR ASPHALT-RUBBER ASTM D570-72

AR Composition	Specimen Age in days	Average absorption in %
AR1000/TP.044 5% Kerosene	1	0.11
	2	0.62
	3	0.92
	7	1.11
	14	1.54
	21	1.57
AR1000/TP.044	1	0
	2	.02
	3	.23
	7	.50
	14	.61
	21	.65
AR1000/TP.027	1	.05
	2	.11
	3	.27
	7	.55
	14	.73
	21	.77
	28	.80
AR1000/TP.027-.044	1	0
	2	.07
	3	.20
	7	.28
	14	.51
	21	.63
	28	.65

TABLE 2

WATER VAPOR TRANSMISSION TEST RESULTS

ASTM E96-72

AR MIX	APPLICATION RATE [Gal/yd^2 (l/m^2)]	WVT (gm/m^2-24 hr)	K (cm/sec)	PERMEABILITY CONSTANT (gm/cm^2-hr-mm Hg.)	PERMS (grains/ft^2-hr-in Hg.)
AR1000/TP.027	0.50 (2.26) 0.75 (3.40) 1.00 (4.53)	4.04 2.27 1.44	$3.07x10^{-12}$ $2.56x10^{-12}$ $2.14x10^{-12}$	$1.52x10^{-8}$ $1.27x10^{-8}$ $1.06x10^{-8}$	.024 .013 .008
AR1000/TP.027-.044	0.50 (2.26) 0.75 (3.40) 1.00 (4.53)	3.50 3.32 1.81	$2.66x10^{-12}$ $3.73x10^{-12}$ $2.69x10^{-12}$	$1.32x10^{-8}$ $1.85x10^{-8}$ $1.34x10^{-8}$	.021 .020 .011
AR1000/TP.044	0.50 (2.26) 0.75 (3.40) 1.00 (4.53)	4.71 2.53 2.11	$3.58x10^{-12}$ $2.84x10^{-12}$ $3.14x10^{-12}$	$1.77x10^{-8}$ $1.41x10^{-8}$ $1.56x10^{-8}$	.028 .015 .013

TABLE 3

ASPHALT-RUBBER TESTING
PERMEABILITY DATA
THIN FILM PERMEAMETER

MIX COMPOSITION*	APPLICATION RATE [gal/yd^2	(l/m^2)]	HYDROSTATIC HEAD [ft	(m)]	PERMEABILITY (K) (cm/sec)
B	0.50	(2.26)	23.40	(7.14)	$3.45x10^{-7}$
B	0.50	(2.26)	11.50	(3.51)	$3.02x10^{-7}$
B	0.50	(2.26)	34.60	(10.56)	$3.96x10^{-7}$
B	0.75	(3.40)	11.50	(3.51)	$4.49x10^{-7}$
C	0.50	(2.26)	11.50	(3.51)	$4.83x10^{-6}$
C	0.50	(2.26)	23.40	(7.14)	$3.45x10^{-6}$
C	0.50	(2.26)	34.60	(10.56)	$2.57x10^{-6}$
C	0.75	(3.40)	11.50	(3.51)	$4.31x10^{-7}$
C	0.75	(3.40)	23.40	(7.14)	$1.75x10^{-7}$
C	0.75	(3.40)	34.60	(10.56)	$1.15x10^{-7}$
C	0.75	(3.40)	11.50	(3.51)	0
C	0.75	(3.40)	23.40	(7.14)	$9.47x10^{-7}$
C	0.75	(3.40)	34.60	(10.56)	$8.60x10^{-7}$
A	0.75	(3.40)	23.40	(7.14)	$4.73x10^{-6}$
B	0.75	(3.40)	36.40	(10.56)	0
A	0.50	(2.26)	11.50	(3.51)	$1.41x10^{-7}$
A	0.50	(2.26)	23.40	(7.14)	$9.62x10^{-7}$
A	0.50	(2.26)	34.60	(10.56)	$9.15x10^{-7}$
A	0.75	(3.40)	11.50	(3.51)	$3.16x10^{-6}$
A	0.75	(3.40)	23.40	(7.14)	$2.37x10^{-6}$
A	0.75	(3.40)	34.60	(10.56)	$2.01x10^{-6}$
A	0.75	(3.40)	69.00	(21.00)	$9.48x10^{-7}$
B	0.50	(2.26)	11.50	(3.51)	0
A	0.50	(2.26)	11.50	(3.51)	$3.85x10^{-6}$
C	0.50	(2.26)	11.50	(3.51)	0
D	0.75	(3.40)	11.50	(3.51)	0
D	0.50	(2.26)	11.50	(3.51)	0
B	0.75	(3.40)	11.50	(3.51)	0

*Mix Composition A = AR1000/TP.044
B = AR1000/TP.027
C = AR1000/TP.027-.044
D = AR1000

TABLE 4

TOUGHNESS/TENSILE PULLOUT TEST DATA
ASPHALT-RUBBER MIXTURES
Temperature 77°C (25°C)

Mix Composition	Test No.	Toughness in in.-#	Average Toughness in in.-#	Increase in Toughness in %*
AR1000	1	37.4		
	2	38.6	38.0	-
AR1000/TP.044	1	141.2		
	2	159.2		
	3	141.6		
	4	147.0	147.3	387
AR1000/TP.027	1	98.2		
	2	87.8		
	3	97.3		
	4	92.5	94.0	247
AR1000/TP.027 -.044	1	126.2		
	2	132.7		
	3	136.0		
	4	130.8	131.5	346

*Increase in toughness over that of the base asphalt.

TABLE 5

MODIFIED BARRETT SLIDE TEST DATA FOR ASPHALT AND ASPHALT-RUBBER

SLOPE: 1-1/2 to 1; TEMPERATURE: 140°F (60°C); TIME: 48 hours

SLIDE NO.	ASPHALT-RUBBER MIX	AGE OF MIX	LENGTH OF RUN* in.	LENGTH OF RUN* mm
Series No. 1		1 day		
1	AR1000	"	12+	305+
2	AR1000	"	12+	305+
3	AR1000/TP.027	"	1.25	31.75
4	AR1000/TP.027	"	1.00	25.40
5	AR1000/TP.027-.044	"	2.00	50.80
6	AR1000/TP.027-.044	"	2.10	53.35
7	AR1000/TP.044	"	8.00	203.20
8	AR1000/TP.044	"	8.25	209.55
Series No. 2		7 day		
9	AR1000/TP.027	"	1.50	38.40
10	AR1000/TP.027	"	1.40	34.00
11	AR1000/TP.027-.044	"	2.12	53.00
12	AR1000/TP.027-.044	"	2.12	53.00
13	AR1000/TP.044	"	8.62	220.00
14	AR1000/TP.044	"	8.87	227.00
Series No. 3		30 day		
15	AR1000/TP.027	"	1.35	34.30
16	AR1000/TP.027	"	1.50	38.10
17	AR1000/TP.027-.044	"	2.20	55.88
18	AR1000/TP.027-.044	"	2.00	50.80
19	AR1000/TP.044	"	7.95	201.93
20	AR1000/TP.044	"	8.50	215.90

*Length of run represents AR1000 asphalt separation only. Rubber aggregate remained in the shape of a cube at the top of the slope.

TABLE 6

VISCOSITY TEST RESULTS FOR ASPHALT AND ASPHALT-RUBBER

AR MIX	VISCOSITY TEMPERATURE 59°F (15°C)	77°F (25°C)	104°F (40°C)
AR1000	3.70×10^6	6.10×10^5	5.76×10^4
AR1000/TP.027	4.00×10^6	1.36×10^6	2.30×10^5
AR1000/TP.027- 044	-	2.32×10^6	4.96×10^5
AR1000/TP.044	9.00×10^6	2.34×10^6	7.50×10^5

TABLE 7

DUCTILITY TEST DATA FOR
ASPHALT AND ASPHALT-RUBBER
ASTM D113-69

Test Speed 5 cm/min. Test Temperature $77^{o}F$ ($25^{o}C$)

Test No.	Mix Composition	Water Temperature, °F	Extension, cm.	Average Ductility
1a 1b 1c	AR1000	77	150 150 150	150
2a 2b 2c	AR1000/TP.044	76.8	15.0 13.0 10.5	12.8
3a 3b 3c	AR1000/TP.044	76.8	11.5 11.7 14.5	12.6
4a 4b 4c	AR1000/TP.027	76.5	33.8 32.8 27.5	31.4
5a 5b 5c	AR1000/TP.044-.027	77.4	23.6 22.8 21.3	22.6